ACTA ACADEMIAE ABOENSIS

MATHEMATICA ET PHYSICA

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INNEHÅLL

ACTA ACADEMIAE ABOENSIS
MATHEMATICA ET PHYSICA I: 1

EIN KRITERIUM FÜR DIE REELLEN ALGEBRAISCHEN ZAHLEN

AUF EINE DIREKTE VERALLGEMEINERUNG DES EUKLIDISCHEN ALGORITHMUS GEGRÜNDET

VON

D:R NILS PIPPING

Z. ZT. LEKTOR DER MATHEMATIK AN DER AKADEMIE ÅBO

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EIN KRITERIUM FÜR DIE REELLEN ALGEBRAISCHEN ZAHLEN, AUF EINE DIREKTE VERALLGEMEINERUNG DES EUKLIDISCHEN ALGORITHMUS GEGRÜNDET.

1. Wir betrachten ein System von $n+1$, $(n \geqq 1)$ *positiven* reellen Werten

$$v_0 \geqq v_1 \geqq v_2 \geqq \cdots \geqq v_n \; (>0).$$

Falls sie alle unter einander *verschieden* sind, bilden wir aus dem gegebenen System n neue Systeme nach der folgenden Regel.

Das μ:te System $(\mu = 1, 2, \cdot\cdot, n)$ wird erhalten, wenn der grösste Wert, v_0, durch den Wert $v_0 - v_\mu$ ersetzt wird, während die Werte $v_1, v_2, \cdot\cdot, v_n$ unverändert gelassen werden.

Die neuen Systeme bestehen dann sämtlich aus $n+1$ *positiven* Werten; falls jedes derselben nur unter einander *verschiedene* Werte enthält, wiederholen wir dasselbe Verfahren in Bezug auf sie alle. Hierbei erhalten wir n^2 neue Systeme, u. s. w. Bei dem ν:ten Schritte werden n^ν neue Systeme erhalten.

So lange kein einziges von den betrachteten Systemen zwei *gleiche* Werte enthält, setzen wir das genannte Rekursionsverfahren fort; die bei dem folgenden Schritte hervorgehenden Systeme bestehen dann aus lauter *positiven* Werten. Falls wir aber ein System bekommen, das zwei *gleiche* Werte enthält, brechen wir das Verfahren ab; in diesem Falle sagen wir daher, dass der Algorithmus *abbricht;* sonst lässt er sich ins *Unendliche* fortsetzen.

Für $n=1$ finden wir offenbar den Euklidischen Algorithmus wieder; nur ist jede Division durch ebensoviele Subtraktionen ersetzt worden, wie die Quote angibt.

2. Es sei ω der Betrag einer reellen Grösse, die ihrem Zahlenwert nach gegeben ist; die Potenzen

$$1, \omega, \omega^2, \cdots, \omega^n$$

sind dann $n+1$ bekannte positive reelle Werte. Wir wenden das oben angegebene Verfahren auf sie an und erhalten hierbei einen eindeutig definierten Algorithmus, den wir *den zu ω gehörigen allgemeinen Algorithmus n:ter Ordnung* nennen.

In Nrr. 3, 4 und 5 werden wir beweisen, *dass der zu ω gehörige allgemeine Algorithmus n:ter Ordnung stets und nur dann abbricht, wenn ω eine algebraische Zahl höchstens vom n:ten Grade ist.*

Diesem Satze gemäss besteht dann folgendes vollständige

Kriterium für die reellen algebraischen Zahlen n:ten Grades.

Eine reelle Grösse ist eine algebraische Zahl n:ten Grades ($n>1$) stets und nur, wenn der zum Betrag derselben gehörige allgemeine Algorithmus n:ter Ordnung abbricht, während der nämliche Algorithmus ($n-1$):ster Ordnung unendlich ausfällt.

Speziell ist die genannte Grösse eine algebraische Zahl 1:sten Grades (d. h. eine rationale Zahl) stets und nur, wenn der zum Betrag derselben gehörige allgemeine Algorithmus 1:ster Ordnung (der Euklidische Algorithmus) abbricht.

3. Die bei unserem Rekursionsverfahren hervorgehenden Wertesysteme schreiben wir in folgender Weise auf.

Zuoberst, in die 0-te Reihe, schreiben wir das Ausgangssystem $\omega^\lambda, (\lambda=0, 1, \cdots, n)$. Allgemein tragen wir in die ν:te Reihe ($\nu \geqq 1$) die n^ν Wertesysteme ein, die aus den $n^{\nu-1}$ Systemen der ($\nu-1$):sten Reihe hergeleitet wurden, und hierbei schreiben wir zuerst die n aus dem ersten System der vorigen Reihe hergeleiteten Systeme; dann folgen die n Systeme, die aus dem zweiten System der vorigen Reihe hergeleitet wurden, u. s. w. Die n Systeme jeder derartigen Gruppe werden schliesslich nach dem in Nr. 1 festgestellten Prinzip geordnet.

Wenn wir mit

$$S_{\mu}^{(\nu)}, \quad (\nu=0, 1, 2, \cdot\cdot; \mu=1, 2, \cdot\cdot, n^{\nu})$$

das μ:te System der ν:ten Reihe bezeichnen, erhalten wir also das Schema

$$\begin{array}{c}\overbrace{\overbrace{\overset{(2)}{S_1}\cdots\cdots\overset{(2)}{S_n}}^{\overset{(1)}{S_1}} \quad \overbrace{\overset{(2)}{S_{n+1}}\cdots\overset{(2)}{S_{2n}}}^{\overset{(1)}{S_2}} \cdots\cdots\cdots\cdots \overbrace{\overset{(2)}{S_{(n-1)n+1}}\cdots\overset{(2)}{S_{n^2}}}^{\overset{(1)}{S_n}}}^{\overset{(0)}{S_1}} \\ \cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\end{array}$$

Jedem System $S_{\mu}^{(\nu)}$ gehören $n+1$ Werte, die wir mit

$$u_{\mu,\lambda}^{(\nu)}, \quad (\lambda=0, 1, \cdot\cdot, n)$$

bezeichnen. Weil unsere Ausgangswerte ω^{λ} sind, können wir

(1) $$u_{1,\lambda}^{(0)}=\omega^{\lambda}, \quad (\lambda=0, 1, \cdot\cdot, n)$$

setzen, und allgemein: wenn wir aus einem gewissen System der $(\nu-1)$:sten Reihe das System $S_{\mu}^{(\nu)}$ herleiten, ersetzen wir den grössten Wert jenes Systems durch einen neuen Wert nach der in Nr. 1 angegebenen Regel *ohne die gegenseitige Reihenfolge der fraglichen Werte zu verändern;* $u_{\mu,\lambda}^{(\nu)}$ bezeichnet dann einen eindeutig definierten Wert.

Nach (1) lassen sich die Ausgangswerte $u_{1,\lambda}^{(0)}$ in der Form

(2) $$u_{1,\lambda}^{(0)}=\sum_{\varrho=0}^{n} p_{1,\lambda,\varrho}^{(0)}\,\omega^{\varrho}$$

schreiben, wo

(3) $$\begin{cases} p_{1,\lambda,\varrho}^{(0)}=1, & (\lambda=\varrho) \\ p_{1,\lambda,\varrho}^{(0)}=0, & (\lambda\neq\varrho). \end{cases}$$

Falls wir sukzessiv mit sämtlichen Koeffizienten p dieselben Operationen ausführen wie mit den entsprechenden Werten u, erhalten wir daher

$$u_{\mu,\lambda}^{(\nu)} = \sum_{\varrho=0}^{n} p_{\mu,\lambda,\varrho}^{(\nu)} \omega^{\varrho}, \quad \begin{pmatrix} \nu=0,1,2,\cdots \\ \mu=1,2,\cdots,n^{\nu} \\ \lambda=0,1,\cdots,n \end{pmatrix} \tag{4}$$

in welcher Gleichung die Koeffizienten p *ganze* Zahlen sind.

Es sei $\triangle_{\mu}^{(\nu)}$ die Determinante

$$\triangle_{\mu}^{(\nu)} = \begin{vmatrix} p_{\mu,0,0}^{(\nu)} & p_{\mu,0,1}^{(\nu)} & \cdots & p_{\mu,0,n}^{(\nu)} \\ p_{\mu,1,0}^{(\nu)} & p_{\mu,1,1}^{(\nu)} & \cdots & p_{\mu,1,n}^{(\nu)} \\ \cdots & \cdots & \cdots & \cdots \\ p_{\mu,n,0}^{(\nu)} & p_{\mu,n,1}^{(\nu)} & \cdots & p_{\mu,n,n}^{(\nu)} \end{vmatrix}$$

Wir haben dann $\triangle_{\mu}^{(\nu)} = \triangle_{\mu_1}^{(\nu-1)}, (\nu \geqq 1)$, wenn wir mit $S_{\mu_1}^{(\nu-1)}$ das Wertesystem bezeichnen, aus welchem das System $S_{\mu}^{(\nu)}$ hergeleitet ist; denn $\triangle_{\mu}^{(\nu)}$ geht aus $\triangle_{\mu_1}^{(\nu-1)}$ hervor, indem man von den Elementen einer gewissen Reihe dieser Determinante die Elemente einer anderen Reihe subtrahiert. Weil $\triangle_1^{(0)} = 1$ ist [vgl. (3)], erhalten wir mithin

$$\triangle_{\mu}^{(\nu)} = 1, \quad (\nu=0,1,2,\cdots; \mu=1,2,\cdots,n^{\nu}). \tag{5}$$

Aus dem Obigen geht nun unmittelbar der Satz hervor:

Wenn der zu ω gehörige allgemeine Algorithmus n:ter Ordnung abbricht, indem ein System $S_{\mu}^{(\nu)}$ mit zwei gleichen Werten $u_{\mu,\lambda_1}^{(\nu)}$ und $u_{\mu,\lambda_2}^{(\nu)}$ erhalten wird, ist ω eine algebraische Zahl höchstens vom n:ten Grade.

Denn nach (4) haben wir unter der genannten Voraussetzung

$$\sum_{\varrho=0}^{n} \left(p_{\mu,\lambda_1,\varrho}^{(\nu)} - p_{\mu,\lambda_2,\varrho}^{(\nu)}\right)\omega^{\varrho} = 0,$$

und nach (5) ist diese Gleichung keine Identität.

4. Umgekehrt nehmen wir nunmehr an, *dass die ihrem Zahlenwert nach gegebene reelle Grösse eine algebraische Zahl höchstens vom n:ten Grade ist,* und wir wollen zeigen, *dass der zum Betrag derselben gehörige allgemeine Algorithmus n:ter Ordnung abbricht.*

Unserer Annahme gemäss genügt der genannte Betrag ω einer Gleichung

$$g_0 + g_1\,\omega + \cdots + g_n\,\omega^n = 0 \tag{6}$$

mit ganzzahligen Koeffizienten.

Wenn wir $g_\lambda = U_{1,\lambda}^{(0)}$ setzen, lässt sich diese Gleichung nach (1) in der Form

$$\sum_{\lambda=0}^{n} U_{1,\lambda}^{(0)}\, u_{1,\lambda}^{(0)} = 0 \tag{6'}$$

schreiben; wenigstens einer von den Koeffizienten $U_{1,\lambda}^{(0)}$ ist hierbei positiv und wenigstens einer von denselben negativ, weil $u_{1,\lambda}^{(0)} > 0$ ist.

Es gilt dann allgemein zwischen den Werten $u_{\mu,\lambda}^{(\nu)}$ eines beliebigen Systems $S_{\mu}^{(\nu)}$ eine Beziehung

$$\sum_{\lambda=0}^{n} U_{\mu,\lambda}^{(\nu)}\, u_{\mu,\lambda}^{(\nu)} = 0 \tag{7}$$

mit ganzzahligen Koeffizienten, von denen wenigstens einer positiv und wenigstens einer negativ ist.

Dass dem so ist, wollen wir sofort vermittels vollständiger Induktion beweisen.

Nehmen wir also an, dass für ein gewisses System $S_{\mu_1}^{(\nu)}$ der ν:ten Reihe die Beziehung

$$(7)' \qquad \sum_{\lambda=0}^{n} U_{\mu_1, \lambda}^{(\nu)} u_{\mu_1, \lambda}^{(\nu)} = 0$$

gilt, in welcher die Koeffizienten $U_{\mu_1, \lambda}^{(\nu)}$ die vorgeschriebenen Bedingungen erfüllen. Wir betrachten das System $S_{\mu_2}^{(\nu+1)}$ der $(\nu+1)$:sten Reihe, welches aus dem System $S_{\mu_1}^{(\nu)}$ in der Weise hergeleitet worden ist, dass der grösste von den Werten $u_{\mu_1, \lambda}^{(\nu)}$ — sei es $u_{\mu_1, \lambda_1}^{(\nu)}$ — durch den Wert $u_{\mu_1, \lambda_1}^{(\nu)} - u_{\mu_1, \lambda_2}^{(\nu)}$, $(\lambda_2 \neq \lambda_1)$ ersetzt wurde.

Wir haben dann

$$(8) \qquad \begin{cases} u_{\mu_2, \lambda_1}^{(\nu+1)} = u_{\mu_1, \lambda_1}^{(\nu)} - u_{\mu_1, \lambda_2}^{(\nu)} \\ u_{\mu_2, \lambda}^{(\nu+1)} = u_{\mu_1, \lambda}^{(\nu)} \qquad\qquad , \quad \neq \lambda_1), \end{cases}$$

und wenn wir

$$(9) \qquad \begin{cases} U_{\mu_2, \lambda_2}^{(\nu+1)} = U_{\mu_1, \lambda_1}^{(\nu)} + U_{\mu_1, \lambda_2}^{(\nu)} \\ U_{\mu_2, \lambda}^{(\nu+1)} = U_{\mu_1, \lambda}^{(\nu)} \qquad\qquad , (\lambda \neq \lambda_2) \end{cases}$$

wählen, erhalten wir nach (7)′, (8) und (9)

$$(7)'' \qquad \sum_{\lambda=0}^{n} U_{\mu_2, \lambda}^{(\nu+1)} u_{\mu_2, \lambda}^{(\nu+1)} = 0.$$

Aus (9) geht hervor, dass n von den Koeffizienten der Beziehung (7)″ mit n von den Koeffizienten der Beziehung (7)′ übereinstimmen, während nur einer von denselben neu ist. Weil ferner wenigstens zwei von den Koeffizienten der Beziehung (7)′ von Null verschieden

sind, verschwinden also die Koeffizienten der Beziehung (7)″ nicht sämtlich; und weil alle Werte $u_{\mu_2,\lambda}^{(\nu+1)}$ positiv sind (vgl. Nr. 1), folgt daher, dass wenigstens einer von den Koeffizienten $U_{\mu_2,\lambda}^{(\nu+1)}$ positiv und wenigstens einer von denselben negativ ist.

Hiermit ist der folgende Hilfssatz gewonnen.

Wenn ω eine algebraische Zahl höchstens vom n:ten Grade ist, gilt für jedes System $S_\mu^{(\nu)}$ zwischen den zu demselben gehörigen Werten $u_{\mu,\lambda}^{(\nu)}$ eine Beziehung

$$\sum_{\lambda=0}^{n} U_{\mu,\lambda}^{(\nu)}\, u_{\mu,\lambda}^{(\nu)} = 0$$

mit ganzzahligen Koeffizienten, von denen wenigstens einer positiv und wenigstens einer negativ ist.

5. Als *Antithese* nehmen wir jetzt an, es sei der betrachtete allgemeine Algorithmus n:ter Ordnung *unendlich.*

Wir haben dann eine unendliche Reihe von Systemen $S_\mu^{(\nu)}$ und eine entsprechende Reihe von Systemen ganzer Zahlen $U_{\mu,\lambda}^{(\nu)}$, $(\lambda=0, 1, \cdot\cdot, n)$, welche die in unserem Hilfssatz angegebenen Bedingungen erfüllen.

Indem wir ein bestimmtes Koeffizientensystem $U_{1,\lambda}^{(0)} = g_\lambda$ fixieren, von welchem wir ausgehen, und ferner die Koeffizienten $U_{\mu,\lambda}^{(\nu)}$, $(\nu \geqq 1)$ nach dem durch die Gleichungen (9) festgestellten Prinzip herleiten, sind die Koeffizienten $U_{\mu,\lambda}^{(\nu)}$ sämtlich eindeutig definiert.

Mit Hilfe derselben greifen wir für jeden Index ν ein gewisses von den Systemen $S_\mu^{(\nu)}$ heraus. Wir bezeichnen es mit $S^{(\nu)}$ und in Analogie hiermit bezeichnen wir die Werte, die dem fraglichen System gehören, mit $u_\lambda^{(\nu)}$, $(\lambda=0, 1, \cdot\cdot, n)$ und die entsprechenden Koeffizienten mit $U_\lambda^{(\nu)}$.

Das System $S^{(0)}$ ist mit dem System $S_1^{(0)}$ identisch; die Systeme $S^{(\nu)}$, $(\nu \geqq 1)$ definieren wir sukzessiv durch folgendes Rekursionsverfahren.

Es sei das System $S^{(\nu)}$ fixiert. Für die Werte $u_\lambda^{(\nu)}$, die demselben gehören, gilt die Gleichung

$$\sum_{\lambda=0}^{n} U_\lambda^{(\nu)} u_\lambda^{(\nu)} = 0, \tag{10}$$

und nach unserer Antithese sind hierbei die Werte $u_\lambda^{(\nu)}$ sämtlich verschieden; der Grösse nach geordnet seien sie

$$v_0^{(\nu)} > v_1^{(\nu)} > \cdot\cdot > v_n^{(\nu)}.$$

Die entsprechenden Koeffizienten der Gleichung (10) bezeichnen wir mit $V_\lambda^{(\nu)}$, so dass diese Gleichung in der Form

$$\sum_{\lambda=0}^{n} V_\lambda^{(\nu)} v_\lambda^{(\nu)} = 0 \tag{10$'$}$$

geschrieben werden kann.

Andererseits ordnen wir auch die Koeffizienten $U_\lambda^{(\nu)}$ der Grösse nach im algebraischen Sinne. Wir erhalten dann eine Koeffizientenreihe, die wir mit

$$W_0^{(\nu)} \geqq W_1^{(\nu)} \geqq \cdots \geqq W_n^{(\nu)} \tag{11}$$

bezeichnen, und hierbei treffen wir die Verabredung, dass wir, falls $U_{\lambda_1}^{(\nu)} = U_{\lambda_2}^{(\nu)}$ und $\lambda_1 < \lambda_2$ ist, in der Reihe (11) den Koeffizienten $U_{\lambda_1}^{(\nu)}$ links von dem Koeffizienten $U_{\lambda_2}^{(\nu)}$ schreiben.

Jede Zahl $W_\lambda^{(\nu)}$ bezeichnet dann einen ganz bestimmten Koeffi-

zienten U. Falls der entsprechende Wert u mit $w_\lambda^{(\nu)}$ bezeichnet wird, nimmt die Gleichung (10) die neue Form

$$\sum_{\lambda=0}^{n} W_\lambda^{(\nu)} w_\lambda^{(\nu)} = 0 \tag{10''}$$

an, und hierbei haben wir

$$W_0^{(\nu)} > 0, \; W_n^{(\nu)} < 0, \tag{12}$$

weil wenigstens einer von den Koeffizienten der Gleichung (10) positiv und wenigstens einer von denselben negativ ist.

Nunmehr sind folgende drei Fälle zu unterscheiden.

1:o. $V_0^{(\nu)} < 0$. *Als das System $S^{(\nu+1)}$ wählen wir in diesem Falle das System, welches aus dem System $S^{(\nu)}$ hervorgeht, indem der grösste Wert, $v_0^{(\nu)}$, durch den Wert $v_0^{(\nu)} - w_0^{(\nu)}$ ersetzt wird, während die Werte $v_1^{(\nu)}, v_2^{(\nu)}, \cdot\cdot, v_n^{(\nu)}$ unverändert gelassen werden.* Die Werte $w_0^{(\nu)}$ und $v_0^{(\nu)}$ sind verschieden, weil $V_0^{(\nu)} < 0, W_0^{(\nu)} > 0$ ist.

2:o. $V_0^{(\nu)} > 0$. *Als das System $S^{(\nu+1)}$ wählen wir in diesem Falle das System, welches aus dem System $S^{(\nu)}$ hervorgeht, indem der grösste Wert, $v_0^{(\nu)}$, durch den Wert $v_0^{(\nu)} - w_n^{(\nu)}$ ersetzt wird, während die Werte $v_1^{(\nu)}, v_2^{(\nu)}, \cdot\cdot, v_n^{(\nu)}$ unverändert gelassen werden.* Die Werte $w_n^{(\nu)}$ und $v_0^{(\nu)}$ sind verschieden, weil $V_0^{(\nu)} > 0, W_n^{(\nu)} < 0$ ist.

3:o. $V_0^{(\nu)} = 0$. Wir haben dann $w_0^{(\nu)} \neq v_0^{(\nu)}, w_n^{(\nu)} \neq v_0^{(\nu)}$, und als das System $S^{(\nu+1)}$ können wir folglich jedes beliebige von den beiden in den Fällen 1:o und 2:o genannten Systemen wählen. Wir treffen die Verabredung, *dass wir dasselbe System, wie im Falle* 1:o *wählen.* —

Von den Koeffizienten $U_\lambda^{(\nu+1)}$ stimmen nach (9) wenigstens n mit n von den Koeffizienten $U_\lambda^{(\nu)}$ überein. Im Falle 1:o wird statt des Koeffizienten $W_0^{(\nu)}$ ein neuer Koeffizient $W_0^{(\nu)}+V_0^{(\nu)}$ erhalten, und im Falle 2:o wird statt des Koeffizienten $W_n^{(\nu)}$ der Koeffizient $W_n^{(\nu)}+V_0^{(\nu)}$ erhalten, während im Falle 3:o die Koeffizienten $U_\lambda^{(\nu)}$ sämtlich unverändert bleiben.

Wenn wir mit $M^{(\nu)}$ den grössten von den Beträgen $\left|U_\lambda^{(\nu)}\right|, (\lambda=0,1,\cdot\cdot,n)$ bezeichnen, haben wir mithin dem Vorigen gemäss

$$\tag{13} \begin{cases} \left|W_0^{(\nu)}+V_0^{(\nu)}\right|<M^{(\nu)} \text{ im Falle 1:o,} \\ \left|W_n^{(\nu)}+V_0^{(\nu)}\right|<M^{(\nu)} \text{ im Falle 2:o,} \end{cases}$$

und es ist daher jedenfalls

$$\tag{14} M^{(0)}\geqq M^{(1)}\geqq\cdot\cdot\geqq M^{(\nu)}\geqq M^{(\nu+1)}\geqq\cdot\cdot.$$

Die Grössen $M^{(\nu)}$, $(\nu=0,1,2,\cdot\cdot)$ sind hierbei positive ganze Zahlen, und daraus lässt sich unmittelbar folgern, *dass es eine Zahl* ν_1 *derart gibt, dass*

$$\tag{15} M^{(\nu)}=M^{(\nu+1)} \textit{ für jeden Index } \nu\geqq\nu_1$$

ist. Denn sonst hätten wir nach (14) eine unendliche Reihe von abnehmenden positiven ganzen Zahlen, was widersinnig ist.

Wir können aber auch ein anderes Ergebnis betreffend Gleichheit oder Ungleichheit in den Beziehungen (14) herleiten.

Unter den Koeffizienten $U_\lambda^{(\nu_1)}$ seien α gleich $M^{(\nu_1)}$ und β gleich $-M^{(\nu_1)}$. *Wenn dann* μ *eine Zahl derart angibt, dass bei der Herleitung der Systeme* $S^{(\nu_1+1)}, S^{(\nu_1+2)},\cdot\cdot, S^{(\nu_1+\mu)}$ *der Fall* 1:o

wenigstens α-mal und der Fall 2:0 wenigstens β-mal eingetreten ist, haben wir nach (13)

$$M^{(\nu_1)} > M^{(\nu_1+\mu)}. \tag{16}$$

Eine Zahl μ der genannten Art gibt es thatsächlich; denn wir können ohne Mühe folgendes beweisen.

a) *Es gibt keine Zahl ν' derart, dass $V_0^{(\nu)} = 0$ für jeden Index $\nu \geqq \nu'$ ist.*

Es seien die Werte $u_\lambda^{(\nu')}$ der Grösse nach geordnet

$$v_0^{(\nu')} > v_1^{(\nu')} > \cdot\cdot > v_n^{(\nu')}.$$

Nach dem Bildungsgesetz des Algorithmus folgern wir mit Hilfe des Axioms von Archimedes, dass wir nach einer endlichen Anzahl Operationen ein System erhalten, in dem der Wert $v_1^{(\nu')}$ der grösste ist, und nach noch einer endlichen Anzahl Operationen ergibt sich ein System, in dem der Wert $v_2^{(\nu')}$ der grösste ist, u. s. w. Früher oder später müssen wir also ein System erhalten, in dem ein beliebiger von den Werten $u_\lambda^{(\nu')}$ der grösste ist.

Einer von den Koeffizienten $U_\lambda^{(\nu')}$ — sei es $U_{\lambda_1}^{(\nu')}$ — ist sicher von Null verschieden. Aus der Annahme $V_0^{(\nu)} = 0$ für jeden Index $\nu \geqq \nu'$ folgern wir $U_\lambda^{(\nu)} = U_\lambda^{(\nu+1)}$, $(\nu \geqq \nu')$ und daher $U_{\lambda_1}^{(\nu)} \neq 0, (\nu \geqq \nu')$. Wenn wir den Algorithmus so weit treiben, dass ein System $S^{(\nu'')}, (\nu'' \geqq \nu')$ erhalten wird, in dem der Wert $u_{\lambda_1}^{(\nu')} = u_{\lambda_1}^{(\nu'')}$ der grösste ist, haben wir also $V_0^{(\nu'')} = U_{\lambda_1}^{(\nu'')} \neq 0$ gegen unsere Annahme.

b) *Es gibt keine Zahl ν' derart, dass $V_0^{(\nu)} \leqq 0$ für jeden Index $\nu \geqq \nu'$ ist.*

Jedes Mal, wenn $V_0^{(\nu)} < 0$ ist, nimmt die Summe Σ_ν von allen positiven Koeffizienten $U_\lambda^{(\nu)}$ ab, während diese Summe unverändert

bleibt, wenn $V_0^{(\nu)}=0$ ist. Nach a) trifft der erstere Fall bei unendlich vielen von den betrachteten Operationen ein, und wenn es einen Index der genannten Art gäbe, hätten wir also eine unendliche Reihe von abnehmenden positiven ganzen Zahlen Σ_ν, was widersinnig ist.

c) *Es gibt keine Zahl ν' derart, dass $V_0^{(\nu)}\geqq 0$ für jeden Index $\nu\geqq\nu'$ ist.*

Jedes Mal, wenn $V_0^{(\nu)}>0$ ist, nimmt die Summe Σ'_ν von allen negativen Koeffizienten $U_\lambda^{(\nu)}$ im algebraischen Sinne zu, während diese Summe unverändert bleibt, wenn $V_0^{(\nu)}=0$ ist. Nach a) trifft der erstere Fall bei unendlich vielen von den betrachteten Operationen ein, und wenn es einen Index der genannten Art gäbe, hätten wir also eine unendliche Reihe von zunehmenden negativen ganzen Zahlen Σ'_ν, was widersinnig ist. —

Nach b) und c) trifft bei der Herleitung der Systeme

$$S^{(\nu_1\pm 1)},\ S^{(\nu_1\pm 2)},\ldots$$

sowohl der Fall 1:o als der Fall 2:o unendlich oft ein, und es gibt daher eine Zahl μ, für welche die Ungleichung (16) gültig ist.

Die Beziehungen (15) und (16) lassen sich aber nicht vereinbaren. Ein Widerspruch wird mithin erhalten, wenn wir annehmen, dass der betrachtete Algorithmus unendlich ausfällt, und *er muss folglich nach einer endlichen Anzahl Operationen abbrechen.*

Hiermit ist der in Nr. 2 formulierte Satz vollständig bewiesen, und die Richtigkeit unseres Kriteriums für die reellen algebraischen Zahlen *n*:ten Grades ist daher dargelegt worden.

6. Eine wesentlich einfachere Verallgemeinerung des Euklidischen Algorithmus als die im Vorhergehenden betrachtete wurde neulich von Viggo Brun[1] angegeben.

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[1] *En generalisation av kjedebrøken* I (avec un résumé en français), Videnskapsselskapets skrifter, I, Mat.-Nat. Klasse, 1919, N:o 6, Kristiania.

Aus dem Wertesystem $v_0 \gtreqless v_1 > \cdots > v_n$ bildet Brun *nur ein* neues System, welches erhalten wird, *wenn man den Wert* v_0 *durch den Wert* $v_0 - v_1$ *ersetzt, während die Werte* $v_1, v_2, \cdots, v_n$ *unverändert gelassen werden.*

Auf die Potenzen $1, \omega, \cdots, \omega^n$ angewendet gibt also der Brunsche Algorithmus die Systemreihe, die wir oben (vgl. Nr. 3) mit $S_1^{(\nu)}, (\nu = 0, 1, 2, \cdots)$ bezeichnet haben, woraus hervorgeht, dass die Überlegungen in Nr. 3 ihre Gültigkeit beibehalten, auch falls wir statt des unsrigen allgemeinen Algorithmus den einfacheren Brunschen betrachten. M. a. W.

Wenn der Brunsche Algorithmus, auf die Potenzen $1, \omega, \cdots, \omega^n$ *angewendet, abbricht, indem ein System* $S_1^{(\nu)}$ *mit zwei gleichen Werten erhalten wird, ist* ω *eine algebraische Zahl höchstens vom n:ten Grade.*

Wir wissen, dass der *umgekehrte* Satz für $n = 1$ gültig ist, denn wie unser Algorithmus ist der Brunsche dann mit dem Euklidischen Algorithmus identisch. Es lässt sich ferner zeigen,[1] dass dem so ist ebenfalls für $n = 2$. In dem allgemeinen Falle aber, wo n eine beliebige positive ganze Zahl angibt, stellen sich Schwierigkeiten ein.

Versuchen wir nämlich denselben Weg einzuschlagen, der in Nr. 5 zum Ziele führte.

Nach unserem Hilfssatz (vgl. Nr. 4) gilt zwischen den Werten $u_{1,\lambda}^{(\nu)}$ des Systems $S_1^{(\nu)}$ die Beziehung

$$\sum_{\lambda=0}^{n} U_{1,\lambda}^{(\nu)} u_{1,\lambda}^{(\nu)} = 0$$

mit gewissen eindeutig definierten ganzzahligen Koeffizienten $U_{1,\lambda}^{(\nu)}$; es sei $M_1^{(\nu)}$ der grösste von den Beträgen $\left|U_{1,\lambda}^{(\nu)}\right|$.

[1] Auf diese Frage gehen wir nicht näher ein, weil Brun in einer noch nicht veröffentlichten Fortsetzung der oben zitierten Abhandlung ein damit äquivalentes Resultat erreicht haben dürfte. (Briefliche Mitteilung an den Verf.)

Um dem Gang der Überlegungen in Nr. 5 zu folgen hätten wir dann zu zeigen, dass die Beziehungen

$$M_1^{(0)} \geqq M_1^{(1)} \geqq \cdot\cdot \geqq M_1^{(\nu)} \geqq M_1^{(\nu+1)} \geqq \cdots \tag{14 a}$$

gültig seien, und dass in denselben Ungleichheit unendlich oft eintrete.

In dem speziellen Falle $n=2$ (und natürlich auch für $n=1$) lässt sich dieser Beweis thatsächlich führen; schon für $n=3$ sind aber die Beziehungen (14 a) nicht mehr gemeingültig, was aus folgendem Beispiel hervorgeht.

Eine Wurzel der Gleichung $2\omega^3+2\omega^2-2\omega-1=0$ ist annähernd $\omega=0{,}8547$; wir erhalten dann

$$u_{1,0}^{(0)}=1{,}0000,\quad u_{1,1}^{(0)}=0{,}8547,\quad u_{1,2}^{(0)}=0{,}7305,\quad u_{1,3}^{(0)}=0{,}6243$$
$$U_{1,0}^{(0)}=-1\ ,\quad U_{1,1}^{(0)}=-2\ ,\quad U_{1,2}^{(0)}=+2\ ,\quad U_{1,3}^{(0)}=+2$$

und ferner

$$u_{1,0}^{(1)}=0{,}1453,\quad u_{1,1}^{(1)}=0{,}8547,\quad u_{1,2}^{(1)}=0{,}7305,\quad u_{1,3}^{(1)}=0{,}6243$$
$$U_{1,0}^{(1)}=-1\ ,\quad U_{1,1}^{(1)}=-3\ ,\quad U_{1,2}^{(1)}=+2\ ,\quad U_{1,3}^{(1)}=+2.$$

Folglich haben wir $M_1^{(0)}=2$, $M_1^{(1)}=3$ und mithin $M_1^{(0)}<M_1^{(1)}$.

Es muss indessen ausdrücklich hervorgehoben werden, dass der betrachtete Algorithmus nichtsdestoweniger abbricht. Falls wir die Rechnungen ausführen, erhalten wir nämlich $u_{1,0}^{(14)} = u_{1,3}^{(14)}$. —

Aus dem Obigen können wir keine bestimmten Schlüsse ziehen, ob man mit Hilfe des Brunschen Algorithmus eine Lösung des Problems von den arithmetischen Kriterien für die reellen algebraischen Zahlen n:ten Grades erhalten kann oder nicht. Wenn man aber den Brunschen Algorithmus durch den unsrigen allgemeineren Algorithmus ersetzt, ergibt sich — wie wir gesehen haben — ein derartiges Kriterium.[1]

Helsingfors, den 2. April 1920.

[1] Für geschichtliche Angaben über die frühere Behandlung des Problems verweisen wir auf die *Vorlesungen über die Natur der Irrationalzahlen* (Teubner, 1892) von Paul Bachmann und auf die Dissertation des Verfassers: *Zur Theorie der arithmetischen Kriterien für die reellen algebraischen Zahlen,* Helsingfors, 1917.

ACTA ACADEMIAE ABOENSIS
MATHEMATICA ET PHYSICA I: 2

ON THE EASTERN PART OF THE ARCTIC BASALT PLATEAU

BY

HELGE G. BACKLUND

PH. D., PROFESSOR OF GEOLOGY AND MINERALOGY, ACADEMY OF ÅBO

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CONTENTS

ON THE EASTERN PART OF THE ARCTIC BASALT PLATEAU.

1. INTRODUCTION.

In a recent memoir A. Holmes[1] has given an extensive petrographical review of the basaltic rocks belonging to the Brito-Arctic province; he points out that descriptions of particular localities and their rocks are not lacking, and that specially the British region has become classic through the well known investigations by Judd, A. Geikie and A. Harker. He fills out the gap existing between other localities of the Arctic region previously described, by an investigation, both petrographical and chemical, of a number of basaltic rocks chiefly from the Atlantic part of the Arctic plateau, sc. from West-Greenland (Hare Island), East-Greenland (Scoresby sound), Iceland, the Faroe Islands, Jan Mayen, Spitsbergen and Franz Joseph Land. The rock specimens described by Holmes were brought home by various expeditions at various times, but their position in space and time is not always strongly defined. In the classification of the arctic basaltic rocks on base of his investigations and on comparison with other recent descriptions of the same or neighbouring regions Holmes divides the basalts in saturated (quartziferous) ones and in undersaturated rocks, the latter comprising both olivine-basalts and nepheline-olivine-bearing rocks; the first group is represented by all localities reviewed by this author except from Jan Mayen, the olivine basalt being the commonest volcanic rock of

[1] A. Holmes, The basaltic rocks of the Arctic region. Mineralogical Magazine, vol. XVIII, pp. 180—223 (Aug. 1918).

all arctic countries, whereon nepheline-bearing rocks were encountered as trachydolerite on Hare-Island and Spitsbergen, [1] as trachyandesite and nepheline-basanite known from Jan Mayen and Spitsbergen. [1] Associated volcanic rocks are andesites (Greenland, Iceland, East Spitsbergen), rhyolites (Iceland) and an alkali-trachyte (Jan Mayen). Throughout all rocks with a few exceptions are equal in salic and femic mineral constituents, and concerning alkalies distinctly sodic. On nine excellent and new analyses, made by H. F. Harwood, the author demonstrates some detailed peculiarities of the region, amongst them the belt of basaltic rocks rich in titanium dioxide and stretching from Hare Island and Scoresby Sound over Iceland to the Faroes; on both sides of this belt the richness in titanium dioxide fades out, the content in feldspar increases; this belt appears indebted to underlying magmatic sources high in titanium dioxide. In conclusion the memoir contains some remarks on „petrographic provinces", the connection of which with terms such as Atlantic and Pacific, alkaline and calc-alkaline Holmes finds not suitable. He attempts to mark out the petrographic series by one of their characteristic members, each series being limited in space and time by distinct geological processes. The andesitic, spilitic, trachydoleritic, and tephritic series are associated the first with compressional and upward movements, the second with compressional and downward movements in regions of sedimentation, the others with differential movements of faulted blocks, a dominant uplift or subsidence in connection with depth of fusion possibly having significance. To all these series basalts are common foundations, and basalts alone are not sufficient to determine the series. The Arctic region represents two series, the andesitic and the trachydoleritic, as lying between two well marked types of petrographic provinces, the tephritic of the Atlantic Islands, and the andesitic of

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[1] These Spitsbergen rocks are described by V. M. Goldschmidt in Vidensk.-Selsk. i Kristiania Skrifter, math.-naturv. kl. 1911. N:o 9.

the Pacific borders. Four sub-provinces are distinguishable in this region, namely the British area, the titaniferous belt, the area of Jan Mayen and younger rocks of northwestern Spitsbergen, and the area of older rocks of Spitsbergen, the basalts of Franz Joseph Land and those of the mouth the Yenisei river with the plateau basalts of the Yenisei-Tunguska region. — The dimensions of the fourth sub-province seem to be much too great compared with the others, and much too variegated by geological processes acting upon it during the volcanic aera of its development to be a simple one; this probable exaggeration in dimensions is caused perhaps by want of knowledge of details upon the North-Siberian plateau. The contributions to the knowledge of the basalts of the Yenisei-mouth,[1] cited by Holmes, are too insignificant to conclude upon the whole eastern region, and the earlier descriptions of some Russian Authors (Polenov, Lavrsky), which embrace great parts of the Lower Tunguska- and Vilui-river basins, are too indefinite and too inanimate and the bulk analyses too incomplete to give an idea either of the character of these basaltic rocks or of their geological position. And finally, it may not be forgotten that the taimyrite, this remarkable nosean- and glassbearing trachytic rock, described by Khrustchoff,[2] probably is of late mezozoic or early tertiary age and belongs to the plateau; no analysis is given of this rock and no definite locality („erratic from the Taimyr-Land") named, but an association with the basalts is more than sure.

A glance at the distribution of these basalts, given by Suess,[3] begins from the south of the amphitheatre of Irkutsk, from Northern Mongolia and the Alps of Tunkinsk and then goes down the river

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[1] H. Backlund, Krist. Gest. v. d. Nordküste Sibiriens I. Mem. Ac. Sei. St. Pétersbourg 1910. XXI. N:o 6.

[2] K. v. Khrustchoff, cited by H. Rosenbusch, Mikrosk. Physiogr. II. 2. 1908 p. 925.

[3] S. Suess, La face de la terre, trad. par E. de Margerie, III. 2. pp. 942—956, peculiarly p. 948.

Yenisei touching the Tunguska plateau and the river mouth, passes through the Atlantic region as far as the mouth of the river Mackenzie; then he mentions the basalts on the Siberian mainland opposite the New Siberian Islands (Cape Svyatoy Noss) and returns to the point of departure over the Yenisei region. There are two gaps to fill out here: the great jump from the river Mackenzie to the New Siberian Islands, and the other from the mouth of the Yenisei to Franz Joseph Land, the first being a very great one, whilst the second is more insignicant and not much greater than between Jan Mayen and Spitsbergen, but of an other character; the space Jan Mayen-Spitsbergen is covered by the ocean and not accessible to detailed investigations, whilst there are between the mouth of the Yenisei and Franz Joseph Land landmasses as Novaya Zemlia, the Solitude Island and the Nicholas Land, waiting for geological elucidation, the first of them in her eastern parts.

The writer had the opportunity to hold in his hands an important material of arctic plateau basalts from regions, which do cover the whole ground of the eastern area as marked out by Suess, and hereto besides some material from the relieved interstices between the Atlantic and the eastern area at the east and the west, and the petrological examination was advanced to the stadium which affords the rock analyses, and some of them were already executed; but then the material was lost and the greater part of the field and laboratory annotations were too, by accident lying outside the writer's power. Only small fragments were saved, and the author believes that it might be of interest to publish them at a moment, when the scientific investigation seems to be awakened to new efforts.

2. GEOLOGICAL FEATURES OF THE PLATEAU.

From the investigations and conclusions by A. Geikie,[1] Suess resumes that the whole plateau region is underlain by a series of great magmatic chambers communicating one with another and being independent in their shape of the mountain chains turned up in earlier time, and stretching through the region in various places. This statement gives some reason to expect basalt flows or rocks associated with them a little here and there, where crustal movements of the underground were favourable to the outburst of volcanic action, however these movements had sufficient amplitude to set down to the very great depths which enclose the magma reservoirs. The difficulty to separate older volcanic rocks associated with the older underground ones, from rocks belonging to the plateau, arises immediately, particularly where the surface conditions or the outburst power was unfavourable to the spreading of lava flows, or these were thrown away by a later erosion. The lack of mesozoic or younger sediments makes the task further difficult.

In the Atlantic region, wherever basalts belonging to this group are encountered, they are associated with upper mesozoic or early tertiary strata; even where the mainland is built up by palaeozoic or earlier rocks as in Eastern Greenland, a narrov coastal stripe of younger mesozoic or tertiary sediments nearly everywhere locates the geographical distribution of these basalts; on the backland basalt is wanted. The earlier basaltflows of Iceland are fixed as tertiary by intercalated fossil bearing beds, while the cone of Beerenberg and the whole island of Jan Mayen seems to be of a more uniform cast without greater unconformities until recent time. The older Spitsbergen basalts (diabases) appear either as caps crowning the table mountains of mesozoic strata dissected by erosion, thus

[1] A. Geikie, The tertiary basalt plateau of North Western Europe. Q. J. G. S. *52*. 1896. pp. 331—406.

representing extrusive lava flows upon a nearly perfect peneplain swept over the relatively undisturbed upper mesozoic sediments of a different age, consequently concealing smaller faults in the bed rock and developing slight unconformities at their base; to this group belong the basalts (diabases) of the north-western Storfiord, beginning from Mt. Teist and Mt. Edlund, culminating in the Mt. Hellwald group near Helis sound, and continuing on the shores of the southern Hinlopen Strait; the greater part of the Franz Joseph Land basalts is also reckoned hitherto. Or these basalts occur as homogeneous sills, simple and multiple, and as dikes of various sizes, as in the eastern part of the Storfiord region, on the shores of Sassen bay, at Cape Thordsen, in Bellsound (Recherche bay and others), and on King Charles Land at the east, always cutting through or enclosed by mesozoic rocks, and air exposed by denudation of different degree; they always seem to be in close alliance with faulting processes.

As a matter of fact, there are two marks which always enable us to discover the tracks of the plateau, namely 1) traces of unfolded sedimentary rocks of upper mesozoic (or tertiary) age, and 2) the erosion base on these, or upon older even undisturbed rocks, the older the rock the greater in value the unconformity; this latter statement fixes these basalts as continental flows. Both these marks have their importance together (when tertiary rocks are absent) or each alone.

3. NEW EVIDENCES OF THE ARCTIC VOLCANIC ACTION.

A short review of the arctic coasts of the Asiatic continent at the far east, as far as they are known, gives us no strong evidences upon occurrences of arctic basalts in their close signification between Behring sound and Cape Svyatoy Noss. Washington describes foyaite and comendite rocks rich in potash, from Cape Deshnev, [1]

[1] H. S. Washington, Igneous rocks from Eastern Siberia. Amer. Journ. of Sc. *13.* 1902, p. 175.

and Lindström gives a bulk analysis of a diabase-aphanite with 6.85 % alcalies from Konyam bay.[1] Neither their age nor their geological position is made mention of. Mesozoic sediments, even in remnants, seem to be wanting there; the broad north going valleys and the flat topped rising ground between the different river systems seem to be an old and largely dissected peneplain with far driven maturity. Raised river beaches or old shore lines marked by basalt flows seem to be wanting. A preliminary revision of the rocks brought home by the 1909 coast survey expedition (Tolmachoff) could not discover any representative of this late group of volcanics. Even from Wrangel Land only older sedimentary rocks (probably of palaeozoic age) are brought home.[2]

The first clear evidences are from the Bennett Island group, including here the small islands in the southeast, as Jeanette and Henriette, and those more advanced to the east, discovered by Wilkitski during the coast survey of 1915. The smaller ones of this group seem to consist entirely of *basaltic volcanics* and rise from the ocean level as steepsided cliffs. The geological structure of Bennett Island is a more variegated one, as shown by the deceased Baron Toll in his last report brought home with his collections two years after his tragic dead (1902). The oldest rock is a black graptolite slate of cambrian age in undisturbed horizontal position, exposed only in the deeper cuts of the island. Upon this floor, with great stratigraphical diastrophism, there rest marly continental deposits containing undeterminable fossil plant remains of jurassic age. The uppermost part of the sedimentary series is a soft yellowish

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[1] G. Lindström, Analyser af bergarter och bottenprof från Ishafvet, Asiens nordkust och Japan. Stockholm 1884.

[2] On the map accompanying the „Explanatory text to the geological map of the part of Siberia investigated by order of the Siberian Railway Comittee“ (St. Petersburg 1906, compiled by L. Jaczevski), there are indicated large areas of „andesite, partly basalt, trachyte and liparite“ on the shore and on the inland immediately west of Behrings sound; no exact report upon these mixed rocks is known to the writer. — On the islands north of the Kolyma-mouth, according to reports of Wrangel there is some possibility to meet with young effusive rocks.

sandstone of tertiary age separated by a denudation plan from the jurassic deposits and filling out the depressions and cavities carved out in these deposits by an earlier erosion. Between the two last mentioned sedimentary members of the series, following the plan of unconformity, one meets with a *basalt* sill of relatively great thickness, well exposed in steep cliffs in the middle part of the south-west coast, whilst the superimposed tertiary sandstone culminates in the highest icecap-covered summit of the island. The sill seems to thin out in the northwestern and southeastern directions no basalts being reported from the hills forming the northwestern and southern capes of the island. Even from the northwestern shore, opposite the highest summit, and from the northern slopes of it no volcanics are reported, though deep erosional depressions seem to run through the island in a northeastern direction. The relations of the basalt to the roofing tertiary sandstone, if the contact is of igneous character or the sandstone of a transgressional type, are not cleared up; the former seems to be true by rate of the rapid outthinning of the basalt sill.

The New Siberian Islands are relatively well known through the investigations by the late Baron Toll and his companions, but until to day no general report is published and not to be expected in the immediate future. Some facts placed to the writer's disposal may be published here. The easternmost island, the true New Siberia, is covered with quaternary deposits without any afflorements of older rocks. Ice drifted boulders and pebbles of basalt of the Bennett type are common upon the shores and are also found on the highest elevations of the flat island. The middle Thaddaeus island represents similar conditions, except on the northern promontory. On the western island, Bielkoff, Kotelnyi and on the cape Bereshnykh of the Thaddaeus Island, palaeozoic sediments of various ages are encountered, the oldest of them being developed as cambrian graptolite slates on the Bielkoff Island by the west. On the shores of the greatest island rocks of silurian, devonian and car-

boniferous age are met with too, well characterized throughout by fossil fauna. The central part of the island, as tested in the upper parts of south running flat river valleys, is built up by mesozoic sediments; the Malakatyn hills covered by quaternary sediments are their culminating point. Only on few points beneath this cover tertiary sediments are preserved. The discovery of mesozoic strata of various ages explains the finding of ammonites by Hedenström during his stay on the island in the former part of the past century and whose report hereupon caused later on lively controversies. The whole region is strongly faulted, partly by concentric step faults, the Nerpalakh bay on the westcoast of Kotelnyi representing a circular stepfault, and partly by radiating faults; this circumstance explains the fact, that palaeozoic rocks are encountered only along the shores, while the mesozoic strata, also strongly faulted and turned up by faulting, build up the central part of the island. In this central part dikes of a *glassy sodaliparite* cut through the mesozoic strata forming low smothed hills in some river valleys. The relations of this volcanic to the tertiary strata are unknown. The rock is light gray, without coloured constituents, containing phenocrysts of quartz and twinned plagioclase feldspar in the glassy groundmass, and in steam cavities infiltrations of secondary silica (opal and chalcedony) are abundant. In the neighbourhood of these dikes an erratic boulder of a finegrained bright reddish granite rich in quartz was met with. Erratic pebbles of this sodaliparite were found also on the islands of New Siberia and Thaddaeus.

The basalts of the opposite mainland are mentioned by Suess; they cut through a gray granite and represent a magmabasalt type, rich in brown glass, phenocrysts of olivine and pyroxene, the feldspars almost quite wanting. Pebbles of basalt are represented from the greater Liakhoff Island.

The continental backland is covered with quaternary and modern fine grained river deposits, the next step of connection being the north slope of the Kharaulakh range on the point where this range

approaches the sea shore between the mouths of the Yana (Ust-yansk = Kazachyé) and the Lena (Tiksibay) rivers. From this point there are reported[1] flows (?) of *columnar basalt and hot springs* connected with them; no advice upon allied sedimentary rocks is given.

From the river Lena crossing the Werkhoyansk range near Bulun no geological news are reported. The geological position of the basalt-(diabase-)sill (?) near Bolkalakh at the mouth of the Olenek amidst sediments of mesozoic age belonging to the mentioned range, is not further elucidated. Upstreams the river Olenek the nearly unbroken basalt plateau joins, extending to the upper Vilui river and its affluents on the one side, to the Anabar and Khatanga rivers on the other side, connecting with the Tunguska plateau and, passing the upper Piasina river, with the basalt of the Yenisei mouth. A reference to the geological individualities of this Siberian basalt plateau in a narrower sense will be given in a further chapter.

From the Alexei Island, between cape Tchelyuskin and the new discovered Nicholas Land, there is brought home a numerous collection of ice drifted pebbles of a typical fine grained diabase (basalt); the whole island is covered with quaternary deposits. By soundings there are drawn up from the sea bottom eastward from the island and southward, in the Thaddaeus bay, several pebbles of a similar diabase, covered with a manganese core. From the Nicholas Land the examined phyllitic slates, folded and contorted, are a proof of the rugged mountain chain reported from there.

Greenstone samples brought home from the shore eastward of the Piasina mouth and from the islands off side the recently discovered Minin bay seem to belong, in spite of their basaltic origin, to an older formation; they are strongly crushed and metamorphosed. On the other hand, the basalt flows of the upper Piasina river, on the Noril Lakes, from where they are reported by Schmidt and others, belong to the plateau and follow the river valley down at

[1] By the last wintering party (1902/1903) of the Baron Toll expedition.

least to the Avam (Dudypta) river confluence, if not farther on; it is a typical surface flow, or several ones, as shown on the shores of the Piasina lake. Along the river downstreams they are markedly bound to the river beaches and the broader old valley has grown young again by the filling lavaflows, the present water wrinkle being compressed by nearly perpendicular cuts through the basalt bed. The connection of these basalts to the Tunguska river plateau passing over the upper Khantaika, Kureika, Kheta and Kotui rivers seems to be uninterrupted. Pebbles of upper silurian fossiliferous limestone on the Piasina lakeshore prove the old age of the floor rocks. The coal measures of the Noril lakes and their metamorphic aequivalents farther south will be made mention of in a further chapter, and some explanation is also be given of the great extension of the mesozoic area as presented on the compilative geological map by Ahlburg. [1]

The diabases of the Yenisei mouth, specially these of the Kuzkin Island, were described earlier by the writer; [2] no new records upon them are reported.

The plant remains of upper mesozoic age from the Solitude Island are strongly silicified, but the short visit of captain Sverdrups expedition of 1915 revealed no volcanic rocks as were to have been expected here. [3]

Erratic pebbles of basalt (diabase) from the Pancratieff Island on the northwest coast of the northern island of Novaia Zemlia were already mentioned by the writer. [3] Since that time there were from this island brought home specimens of diabase (basalt) from the

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[1] Joh. Ahlburg, Die neueren Fortschritte in der Erforschung der Goldlagerstätten Sibiriens. Zeitschrift für prakt. Geologie 1913, p. 105.

[2] Holmes (l. c. p. 221) supposes that the Kuzkin Island is identical with the Sibiriakoff Island; on older Russian maps the Kuzkin Island lies nearer the shore and is outfitted with the excellent harbour Port Dickson, meanwhile the Sibiriakoff Island is situated farther westward.

[3] H. Backlund, On fossil plants from Solitude Island. Geol. Fören. i Stockholm Förh. *38.* 1916, p. 265.

east coast on the same latitude. The basalt crowns undisturbed sediments of mesozoic age, and seems also to occur as concordant dikes in this formation, the last strongly contrasting against the palaeozoic folded strata on the west-coast and representing by this means some ressemblance to the geological features of West-Spitsbergen. The relations of the geological structure of the east- and west-coast are not revealed on account of the central covering ice cap.

At last Franz Joseph Land by Suess is referred to the Petchora plain,[1] the former being the supposed extreme northern continuation of the latter. Already Count Keyserling, during his travels in the Petchora Land in 1843, encountered glacial drifted boulders containing marine fossils of upper jurassic age in the Bolshezemelskaia tundra. Later on, the original localities of jurassic rocks were stated on the southern shore of the river Petchora near the Ishma confluence. In 1909 jurassic red clay deposits, containing *Cardioceras alternans* v. Buch and *Aucella Bronni* Lahus. as characteristic fossils determining their age as sequanian, were reported from the river Adzva, about 100 kilometres north of the confluence with the river Ussa, thus from a locality in the central part of the tundra. Only small remnants of these sediments preserved from glacial erosion are reported. Immediately in the neighbourhood of these deposits several small outcrops of a dissected *basalt surface-flow,* perfectly glacial-smoothed, are met with on the river Adzva; the hills are partly covered with glacial deposits, but the geological relations of the basalt to the older sediments developed on the river, *vic.* to the carboniferous southward (*Productus*-limestone), to the permo-carboniferous (sandstone with plant remains) and, as mentioned before, to the upper jurassic clay in the nearest vicinity are not closely examined, unless they cut the former two formations. However, fragments of a sedimentary rock having great ressemblance to the jurassic clay and enclosed in the

[1] E. Suess, l. c. p. 945: „— — — ces îles affectent une structure tabulaire; elles sont situées entre les branches des Ouralides, et il est permis de considérer le plateau comme un prolongement de la plaine de Petchora — — —“.

basalt flow suggest an upper mesozoic or even tertiary age. Even some evidence, that a strong denudation of sedimentary rocks has swept over the country before the basalt outbreak, is given by the transgressional position on the permo-carboniferous met with in the few points where the floor rock was accessible to observations. This confirms the statement above that the outbreak took place in continental conditions. Another proof of the youth of the basalt is given by a spring of constantly elevated temperature (earlier determinations + 32° C, later ones + 28° C), which penetrates the *Productus*-limestone only a few kilometres further south of the Pymva-you river, left hand affluent of the Adzva; the spring is known since 1828 and tests the postvolcanic action by abundant sinter deposits. Although there is no strong evidence of the late mesozoic or early tertiary age of this basalt, and consequently no certainty of the rock belonging to the arctic plateau basalt, the characteristics are quite significant and uniform.

The basalts (diabases) of the Timan hills further westward are reported as being of palaeozoic age; they are rich in zeolite nodules. The basalts (diabases) of the Kanin peninsula, as described by Ramsay,[1] also seem to be of palaeozoic age, as the copper-bearing melaphyres and augitporphyrites too of the Novaia Zemlia's southern island.

Herewith the ring around the pole is closed; some closer characteristics of the eastern basalt representatives of the Arctic plateau are to be given in the following chapter.

4. PETROGRAPHICAL DESCRIPTION OF ROCKS AND ANALYSES.

A. Basalts from the farthest east.

a. *Bennet island.* The basalt from this island is, as far as can be judged from hand-specimens, medium grained and rich in zeolite patches and cavity fillings, the zeolites partly being so intimately

[1] W. Ramsay, Beiträge zur Geologie der Halbinsel Kanin. Fennia *32* (1911—1912) N:o 7.

grown together with the dark brownish rock, that it is impossible to separate them from the groundmass; the transition between rock and zeolites themselves by intergrowth is completely gradual and in places projecting only as indistinct spots instead of unsharp phenocrysts in a normal porphyritic rock; there is no part of the rock without these spots.

The true amygdale minerals are represented by icositetrahedrons of *analcite*, measuring until 3 cm in diameter; the milky white crystals are sharp faced and seldom pink cloudy dulled. Optically they are anomalous, with biaxial sectors of low birefracting power alternating with isotropic patches and stripes. —

On radiating, slender shaped prismatic crystals forming imperfect sphaerocrystals, the following optical properties were determined:

elongation positive, plane of axes lying in the zone of prisma, γ—acute bissectrix, thus $\gamma = c$;

on flat shaped splinters, quite normal to β, in immersion liquid was found

$$\alpha = 1.478 \pm 0.001$$
$$\gamma = 1.489 \pm 0.001.$$

On thin section by measuring with Babinets compensator:

$\gamma - \alpha = 0.011[74]$, thickness 0.0737 mm.

$\gamma - \beta = 0.008[04]$ „ 0.0711 „ .

On free splinter with Babinets compensator:

$\gamma - \alpha = 0.008[35]$ „ 0.1187 „ ;

thus $\beta = 1.481$

and $\beta - \alpha = 0.003$;

from the refractive indexes calculated:

$$2V\gamma = 63^\circ\ [18']$$
$$D_{21^\circ.5} = 2.183.$$

All these constants agree well with *natrolite*. —

Another group of radiating coarse crystals with bright cleavage-surfaces and pearly lustre on them is intimately bound to the natrolite radiatings forming their immediate ulterior growth; the individuals are flat shaped, nearly leaved according to the best

developed cleavage-plane. Cleavage-flakes give good biaxial figures, with central emergence of the acute bissectrix γ, and the plane of optical axes is normal to the elongation, consequently $\beta = c$ with nearly straight extinction. The other cleavage-direction, nearly of equal perfectness and perpendicular to the just mentioned, gives the central emergence of the obtuse bissectrix α. Thus the optical orientation can be noted as nearly:

$$a = \alpha$$
$$b = \gamma$$
$$c = \beta$$

Further on the following measurements in daylight were executed on the mineral with immersion liquid on free splinters of good orientation:

$$\left.\begin{array}{l} \perp \gamma \begin{cases} \alpha = 1.525 \pm 0.001 \\ \beta = 1.527 \pm 0.001 \end{cases} \\ \perp \alpha \begin{cases} \beta = 1.527 \pm 0.0005 \\ \gamma = 1.539 \pm 0.0005 \end{cases} \end{array}\right\} \quad \begin{array}{l} \text{from these terms calculated:} \\ 2\,V\gamma = 51^\circ\,12' \\ 2\,E\gamma = 82^\circ\,34'; \end{array}$$

with the compensator of Babinet on free splinter:

$\perp \gamma : \beta - \alpha = 0.0032$, thickness $= 0.1326$ mm.;

on thin sections:

$\perp \alpha : \gamma - \beta = 0.0113$, „ $= 0.0754$ „

$\perp \beta : \gamma - \alpha = 0.0145$, „ $= 0.0312$ „ ,

which measurements agree well with the birefraction values calculated from the refractive indexes.

By means of the Wright micrometric ocular-scale there was found

$$2\,E\gamma = 81^\circ\,40',$$

and a control measurement with camera lucida and rotation disc gave

$$2\,E\gamma = 82^\circ,$$

in good agreement with the above calculation.

A closer examination of thin sections developes a feeble striation quite normal to c, the sections normal to γ and α being broad vic. narrow columnar shaped, and normal to β elongated rectangular, and the extinctions sometimes sensibly deviating from the crystallographical axes assumed as orthorhombic by the cleavages // (010)

— perfect and // (100) — less perfect, and by the striation // (001). The deviation attains until 8°.3 on (010) and 4°—5° on (100) [$c:\beta$], the mineral being sometimes triclinic, but nearly and mostly orthorhombic.

Microchemical tests detected abundant lime, but also soda.

The optical properties indicate a mineral of the thomsonite group, the birefraction being too low and the refractive indexes too high as compared with the dates of Michel-Lévy and Lacroix,[1] the axial angle corresponding better to the values of Des Cloizeaux,[2] found on thomsonite from various localities. A series of controlling determinations of the birefraction of thomsonite made by Césaro[3] on thomsonite from nearly the same localities as that served to Des Cloizeaux gave lower values lying between 0.0026 and 0.0042 for $\beta-\alpha$

„ 0.0096 „ 0.011 „ $\gamma-\beta$

„ 0.013 „ 0.014 „ $\gamma-\alpha$,

and of the axial angle $2E\gamma = 82°-85°$, and agrees better with the terms above. Prior[4] states that the double refraction of thomsonite sinks below the double refraction of stilbite (desmin), whose birefraction as given by Michel-Lévy and Lacroix[5] attains 0.006 ($\gamma-\alpha$) on columnar sections, which sections on thomsonite give the birefraction varying between $\beta-\alpha$ and $\gamma-\beta$, as given above; these terms rise to 0.006 ($\beta-\alpha$) and 0.022 ($\gamma-\beta$), conformable to the French authors. These discrepancies cannot be explained only by varying content of soda and lime in the specimens examined optically, because the analyses corresponding to the thomsonites from localities examined by Césaro show only small variations in these constituents, the raised refractive indexes perhaps being a test of heightened lime content, but the lowered double refraction probably connecting with the physical conditions during or after the mineral growth; the in-

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[1] A. Michel-Lévy et A. Lacroix, Les minéraux des roches, p. 320.

[2] Cited after Dana's System, 6th ed., p. 607.

[3] G. Césaro, Bulletin d. l. Classe des Sciences de l'Acad. Roy. de Belgique, 1908, pp. 255—257.

[4] G. T. Prior, On Sphaerostilbite. Mineralogical Magazine *12*. 1900. p. 27.

[5] L. c. p. 319.

vestigations of Rinne[1] upon change of optical properties on zeolites by heating state lowering of the birefracting power ($\gamma - \alpha$) on thomsonite. —

On the free ends the radiating groups of the thomsonite are often covered with small radiating sheaves of a weathered yellowish mineral of a much stronger birefracting power on the cleavage flakes, but showing emergence of the optic normal (β) and an extinction angle ($c:\gamma$) of about 18°, all that on the extremely few parts of the mineral, which are not changed into isotropic substance. The shape of the mineral and these few optical indications point to altered *laumontite.*

In the specimens brought home, no primary calcite nor silica minerals were detected amongst the amygdale and vesicle fillings, whose order of deposition is:

analcite,
natrolite,
thomsonite,
laumontite,

an order which denotes an increasing water and lime content during the gradual cooling of the rock in the late magmatic and postmagmatic (hydrothermal) stage of development, corresponding to a decrease in soda, an inverted sequence as compared with the early and true magmatic stage. —

In thin sections the rock exposes an intersertal structure with phenocrysts of plagioclase feldspar and olivine only slightly exceeding the groundmass minerals by dimensions. The phenocrysts of plagioclase are slightly twinned and distinctly zoned with a core corresponding to $Ab_{35}An_{65}$ and an envelop of 45 % An; the outer contour of the plagioclase grasps in the groundmass by slight dentification. The lath-shaped groundmass-plagioclases are simple albite-twins with uneven border and an anorthite-content of 40--45 % and lower;

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[1] F. Rinne, Sitz.-Ber. Berliner Akademie *46.* 1890. p. 1174.

they are partly changed to thomsonite. The mafic constituents predominate, but they are much decomposed: the olivine phenocrysts are nearly almost replaced by a homogeneous mineral with strong pleochroism (pale yellow to greenish brown) and high double refraction, biaxial negative with medium axial angle and a distinct cleavage normal to the acute bissectrix. These pseudomorphs are closely suggestive of the produce received by Thaddéeff[1] on heating olivine rich in ferrous silicate. The few unaltered remnants of fresh olivine allowed no definite determination of the ferrous silicate content by means of refractive indices. The pale brown augite forms by dimensions the proportional transition to the groundmass; it is much altered by late magmatic influence, partly to chlorite and partly to a mineral of the serpentine group, and builds also up glomerophyric aggregates, intermixed with magnetite grains and ilmenite needles. Apatite needles are seen chiefly as inclusions in the plagioclase phenocrysts, but also in residual interstices. A strange appearence offer the great pseudophenocrysts of thomsonite corresponding to the zeolite patches mentioned above: they are surrounded by a narrow envelop of analcite and small quantities of natrolite needles, and although formed later than and at the expense of the enveloping minerals, as shown on sections normal to the zone of prisma, they imitate closely veritable phenocrysts. — The small residual interstices are filled out by small quantities of analcite, and locally also natrolite needles are seen, but their quantity is unimportant. No strong evidences of glassy residue were detected.

Since the mineral composition is being altered (hydrothermally?) and no rock fragment free from zeolite patches for analytical investigation is obtainable, the measurement of the actual mineral composition by the Rosiwal method was not undertaken; nevertheless an analysis of a specimen poor in zeolite was executed by Dr. N. Sahlbom, and gave the following results:

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[1] K. Thaddéeff, Die Olivingruppe. Zeitschr. f. Krystallographic *26* 1896. p. 60.

	1	A	B	Molecular numbers	Molecular per-cent.	1. Mineral composition („Norm")		Figures of Osann
SiO_2	44.43	44.49	45.08	0.741	50.71	*Or* 5.45	*F*. . 56.40	*s* . . . 50.7
Al_2O_3	18.61	13.05[1]	14.21[2]	0.183	12.10	*Ab* 19.34		*A*. . . 3.1
Fe_2O_3	3.48	2.78	2.28	0.022	—	*An* 31.41		*C*. . . 8.1
FeO	6.62	8.24	8.59	0.092	9.22	*Cor* 2.33		*F*. . . 26.0
MgO	10.14	11.23	7.01	0.254	16.82	Σ*sal* 58.73		*n* . . . 7.4
CaO	6.78	8.58	10.20	0.121	8.05			*a* . . . 1.7
Na_2O	2.29	3.16	3.99	0.037	2.45	*Hy* $MgSiO_3$ . . . 13.47	*P*. . 17.15	*c* . . . 4.3
K_2O	0.92	2.25	1.79	0.010	0.65	$FeSiO_3$ . . . 3.68		*f* . . . 14.0
H_2O at 105°	1.58	0.55	0.15	—	—	*Ol* Mg_2SiO_4 . . 9.15	*O*. . 11.69	*k* . . . 0.83
$H_2O > 105°$	2.44	0.76	0.75	—	—	Fe_2SiO_4 . . 2.54		*T*. . . 0.95
CO_2	0.02	0.86	2.42	0.001	—			
TiO_2	1.70	2.60	2.93	0.021	—	*Ap* 0.71		
P_2O_5	0.33	0.92	0.62	0.002	—	*Il* 3.22	*M*. . 8.25	
Cl	none	—	trace	—	—	*Mt* 5.03		
S	trace	—	0.09	—	—	*Calcite* 0.05		
MnO	0.25	0.17	0.22	0.004	—	Σ*fem* 37.80		
NiO	trace	0.07	none	—	—			
BaO	0.02	—	0.11[3]	0.0001	—	H_2O . . . 4.02		
	99.61	99.71	100.41		100.00	100.55		
Spec. gr.	2.861	—	3.01			Magmatic symbol: III, 5, 4, 4		
						Auvergnose		

1. Olivine-trachydolerite, Bennet island. Dr. N. Sahlbom, analyst.

A. Olivine-trachydolerite, volcanic neck Mt. Halvdan, Spitsbergen. Prof. Dittrich, analyst.[4]

B. Olivin-trachyandesite, Mary Muss bay, Jan Mayen. Dr. Harwood, analyst.[5]

Although the analysis differs conspicuously from those of the normal Arctic basalts in the low silica and high alumina content, the magmatic symbol is nearly accordant with the bulk of them,

[1] Including 2.10 % ZrO_2 and 0.02 % Cr_2O_3. [2] Including 0.05 % V_2O_5 and 0.01 % Cr_2O_3. [3] Including 0.05 % SrO.

[4] V. M. Goldschmidt, l. c.

[5] A. Holmes, l. c. p. 204.

thus giving a slightly erroneous idea of the true character of the rock. It was stated above that the mafic minerals predominate, the „norm“, on the contrary, states a slight predominance of salic constituents, since all lime and alumina are drawn to the salic group, though a great part of them is mafic. The figures of Osann enlisted above give a picture of more concordance with the true proportion, the great value of *f* being significant.

The classification of this rock presents some difficulty. Above analyses of two rocks from the western Arctic basalt region are tabulated, but they differ in lower alumina content and in high alkalies, specially in potash. Moreover, in the Jan Mayen rock lime dominates over magnesia, thus the salic characteristic is more salient and the rock pointed out as alkaline by the normative (and actual) nephelite content; the same is valid to the Mt. Halvdan rock only on part of alkalies, all these marks being absent in the Bennet island-rock. Yet a comparison is made, because the high alumina does not conform with the demands of proper basalt.

It is seen, that whilst in the early magmatic stage of the rock the progressive crystallisation marked a decreasing lime content of the salic constituents (plagioclase), yet the late magmatic stage continuing in the postmagmatic creations marks an inverted development with increasing lime content to the end of crystallisation, partly issued after the complete consolidation of the rock. If the inversion point, marked by the hiatus in cristallisation between plagioclase low in lime and analcite, is to be pushed backward to the earlier magmatic stage, or, in other words, the rock magma in early stage of crystallisation is to be supersaturated with a rising quantity of overheated steam, then the zeolite phase of the rock will begin before the groundmass is solidified (this moment being pushed forward) and a part of the minerals, specially these which are alkalibearing, will be bucked out and deposited in steam cavities, whilst the minerals richer in lime partly resist and partly alter in zeolite; this alteration in case of plagioclase $\rightarrow$ thomsonite is ac-

companied by rising content of alumina, water, and partly lime, by lowering of the content of alkalies (soda) and silica and by lowering of the specific gravity of the rock. Only in this way the early cristallisation of thomsonite is intelligible and the forming of its pseudophenocrysts is drawn into true light. The real content of soda zeolites in the rock is very low, as showed by the analysis figures, yet amongst the cavity mineral they predominate, and the relative soda content in each of them exceeds the soda content in the albite alone.

That something of this kind has worked out the actual stage of the rock, whose mineral composition is not due to the weathering process, finds a confirmation in the mode of olivine-alteration and perhaps in the lowered birefraction of the thomsonite mineral. Yet this process does not exclude an original rock of the calc-alkali series, if not the order of zeolite-separation might strengthen an alkali affinity. The olivine rich in ferrous silicate gives identical hints. The statement by Holmes,[1] that among the volatile fluxes of the alkali series carbon dioxide was a dominant member, cannot be strengthened in this case, no carbonate mineral having been found among the cavity fillings and only traces of them in the rock.

In consideration of this the writer resolved to rank the rock among the trachydolerites of the alkali series unless a hasty examination of both the rock and the analysis should rank her with the common basalts. Except alumina and alkali content and the lower percentage of titanium dioxide, perhaps individual, the analysis agrees well with the analysis of the olivine-trachydolerite of Mt. Halvdan.

b. *Wilkitski-island.* This little island east of the Jeannette and Henriette islands is represented by the material brought home by the Hydrographic Expedition of lieut. B. Wilkitski in 1913. There

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[1] A. Holmes, On the tertiary volcanic rocks of Mozambique. Q. J. G. S. *72.* 1917. p. 253; this statement agrees quite well with the fact of increasing lime-content to the end of the postmagmatic stage, the present rock going not farther then to lime-silicate and not reaching the carbonate stage.

are specimens representing partly a dense rock of darker or lighter steel gray coloured groundmass with sparingly dispersed phenocrysts of yellow olivine not exceeding 1 mm. in diameter; the air exposed surface of this rock is covered with a thin and smooth, rusty brown oxidation crust suggestive of desert varnish. Partly the specimens are slaggy and vesicular, representing lava flows, with rusty brown or glassy black surface and empty, no mineralized and smoothvalled vesicles, the rock being without visible phenocrysts. All specimens are of great freshness.

Under the microscope the darker dense rock reveals two generations of all chief mineral constituents: olivine, augite, the lenads and perofskite, the feldspars quite wanting.

The phenocrysts of olivine reach the greatest dimensions, and the greatest among them show a zoned structure with stronger birefracting envelop and rounded crystal forms of hyalosideritic character. The axial angle is always negative. On a section $\perp \gamma$ of a well zoned phenocryst a measurement of refractive indices gave the following results:

in the core $\alpha = 1.670 \pm 0.001$, $\beta = 1.687 \pm 0.001$

in the envelop $= 1.706 \pm 0.001$, $= 1.731 \pm 0.001$;

the double refraction measured with the compensator of Babinet upon a microphenocryst without zonar structure, thus corresponding to the envelop of the greater crystals, gave the following figure

$$\gamma - \alpha = 0.0423, \text{ thickness } = 0.022 \text{ mm.}$$

consequently $\gamma = 1.748 \pm 0.0015$.

From the determination diagram of the olivine group, based upon the change of refractive indices in connection with the varying chemical composition,[1] the core of the olivine is found to contain about 19 % Fe_2SiO_4, or 18 % FeO, and the envelop about 36—37 % of the Fe-silicate, or 32 % FeO, thus the latter nearly according with hyalosiderite (34 % Fe_2SiO_4, or 30 % FeO). Since the micropheno-

[1] H. Backlund, Über die Olivingruppe. Trav. Mus. Geol. Acad. Imp. Sciences. St. Pétersbourg. *3.* 1909. p. 77.

crysts strongly predominate, the medium olivine may be admitted as of hyalosideritic composition. The core of olivine contains no inclusions, only the outer envelop shows scarce rounded drops of brown perofskite. — The second place in order of crystallisation belongs to nephelite; only rarely he reaches the dimensions of true phenocrysts, and then in intimate connection with olivine, forming a parallel farther growth of idiomorphic olivine phenocrysts, as a colourless likewise idiomorphic shell. The crystallographic axes *c* of both individuals are parallel, thus the axis of optical symmetry ω (nephelite) is parallel to β (olivine). Yet generally the dimensions rest below 0.04×0.03 mm, and in contrast to the groundmass-nephelite he is free of inclusions; by this means it is possible to distinguish the nephelite microphenocrysts from the groundmass ones nearly equal in dimensions: the latter shows abundant central inclusions of apatite, augite, and sparingly magnetite. Both refractive indexes of the nephelite phenocrysts rise above the refractive power of the balsam ($n = 1.5354$), while for the groundmass ones were fixed $\varepsilon \geqq 1.5354$, $\omega < 1.5354$. Consequently a zonar structure with a core of higher refracting power was proved on the phenocrysts; perhaps the core contains some quantities of RO-oxides (BaO?). — The microphenocrysts of magnetite are either built up by glomerophyritic accumulations of several inviduals to a rounded grain, or they show sharp octahedrons. He is later im order of crystallisation than the greater part of the olivine microphenocrysts, because in glomerophyritic accumulations of olivine, which are suggestive of „olivine-bombs", he forms the cement together with nephelite and analcite. Diminishing in dimensions he passes into the groundmass-magnetite. No sure tests upon titanium-content of the magnetite were shown, but his near relations to perofskite makes such a one probable. — The augite-microphenocrysts are pale yellow with brown-purplish tints. The core is free from magnetite inclusions, but contains short needles of apatite and square sections of nephelite; an outer zone is overloaded with magnetite inclusions

and corresponds in time to the initial growth of the first generation of magnetite; the envelop is relatively free from magnetite inclusions and corresponds to the crystallisation of the groundmass-augite. The contour of the augite is pointed out by a garland of magnetite, melting up together the dentification of the envelop. He forms elongated prisms (10 : 1), rarely flattened after (100), and then twinned; sometimes the prisms in their parallelism point out a fluctuation structure. Extinction angles measured on sections strongly $\perp \beta$, gave:

$c : \gamma = 47°.3$ in the distinct core,

$= 48°.5 - 53°.4$ in the intermediate zone, gradual transition,

$= 55°.5$ in the outer shell.

The double refraction, measured with the compensator of Babinet, gave

$\gamma - \alpha = 0.021[3]$, thickness $= 0.030$ mm., with $n = 1.7$.

Axial angle: $2E\gamma = 114° 40'$, in the intermediate zone

$= 119°$, in the core

$$\left.\begin{aligned} 2V\gamma &= 59° 20' \\ &= 61° \end{aligned}\right\} \text{calculated for } \beta = 1.7$$

$$\text{Dispersion of axes: } \left.\begin{aligned} &A - \varrho < v \text{ strong} \\ &B - \varrho > v \text{ weaker} \end{aligned}\right\} \text{around } \gamma$$

An irregural fissuring of the augite does not allow a measurement of the refractive indexes. The dispersion of extinction is considerable as tested on different interference tints on both sides of the extinction, and conformably to the axial dispersion: $c : \gamma_\varrho < c : \gamma_v$. The optical properties test an augite perhaps rich in titanium (dispersion!) and lime (? double refraction) content, containing soda too (extinction angle!).

The groundmass is very finely grained and inverted intersertal: the narrow and long prisms of augite build up a network, whose meshes contain the colourless constituents and partly needles of apatite, and whose nodes are represented by olivine individuals. In case of diminishing grain, which happens in „Schlieren", the meshes lessen and their content too, the augite prisms growing thicker. The magnetite grains are confined along the augite prisms.

The order of crystallisation is the same as pointed out for the phenocrysts, yet the nephelite-forming period closes after the growth of the greater part of augite. The last residue is a colourless cement with a refractive power much inferior to that of the nephelite and of the balsam; sometimes there are seen tracks of cleavage and crystal forms indicating analcite. Belonging to the optical properties of the groundmass constituents, they agree well with those of the phenocrysts: the olivine always points out a hyalosideritic composition, the augite shows hourglass structure, the nephelite is lower in refractive power. Among the nephelite sections there are some rounded of lower refractive power than the bulk of groundmass nephelite and higher than analcite, containing central inclusions of magnetite: the dimensions of the sections were too small to test if there really is leucite, yet the probability is close. — No traces of melilite were tested.

As accessory mineral great and sharp dodecahedrons of yellowish brown perofskite are characteristic; sometimes the crystal forms are wanted and it becomes drop formed, with a broad border of black magnetite, which is developed on the crystals too. The transition between core and border is gradual, by increasing intensity of tint. Cleavage cracks [(100) and (111)] are always well developed, the mineral is completely isotropic and is wanting inclusions. — No signs of weathering or secondary alteration are visible in the rock.

In the lighter rock, which in mineral composition agrees well with the just described one, the perofskite-mineral is more abundant and descends in the groundmass too, partly and to great extent replacing the magnetite.

The slaggy and vesicular scoriaceous rock contains foreign inclusions of pebbles and sedimentary rock fragments. The groundmass in this rock is not differentiated showing dominating brown glass. In the dark coloured mass the few square and hexagonal sections of nephelite appear as windows. The olivine shows all transitions from yellow-brownish pleochroitic substance with the

strong birefraction of the starting mineral to completely dull pseudomorphs of iron oxide, due to late overheating of the outer parts of lava by escaping steam and gas masses during the eruption. — The vesicles are empty.

An incidental estimation by the Rosiwal method of the mineral composition of the darker dense rock by volume is tabulated as follows:

Minerals:	Volume %:
Apatite	2.1
Magnetite and perofskite	6.0
Colourless minerals	44.5
Olivine and augite	47.4
	100.00

This rock was analysed by Dr. N. Sahlbom with the following results:

	2	A	Molecular numbers	Molecular per-cent.	2. Mineral composition („Norm")	Figures of Osann
SiO_2	41.18	44.66	0.686	45.72	*Ne* ... 23.29 } *L*..37.68	*s* ...45.7
Al_2O_3	11.69	12.97	0.115	7.23	*Lc* ... 14.39	*A*... 7.2
Fe_2O_3	5.41	3.84	0.034	—	Σ*sal* 37.68	*C*... 0.0
FeO	7.94	7.55	0.110	11.50		*F*...39.8
MgO	10.58	9.35	0.265	16.63	*Di* $CaSiO_3$ ... 8.00	*n*... 7.4
CaO	9.58	8.82	0.171	10.87	$MgSiO_3$ ... 5.50 } *P*..21.26	*a*... 3.1
Na_2O	5.88	4.24	0.095	5.99	$FeSiO_3$ ... 1.75	*c*... 0.0
K_2O	3.08	2.78	0.033	2.06	*Ac* ... 6.01	*f*...16.9
H_2O at 110°	0.11	0.48	—	—		*k*... 0.55
$H_2O > 110°$	0.17	0.69	—	—	*Ol* Mg_2SiO_4 ..14.70	*M*..12.84
CO_2	none	none	—	—	$FeSiO_4$.... 5.20 } *O*..29.33	*M'*.. 0.82
TiO_2	2.34	2.76	0.029	—	*Am* ... 9.43	
P_2O_5	1.25	1.10	0.009	—		
Cr_2O_3	—	0.01	—	—	*Il* ... 4.41 } *M*.. 9.28	
MnO	0.3	0.21	0.005	—	*Mt* ... 4.87	
NiO	none	0.26	—	—	*Ap* ... 2.79 *A*.. 2.79	
BaO	0.07	—	0.001	—	Σ*fem* 62.66	
	99.65	99.71		100.00	100.34	
Spec. gr.	3.045	—			Magmatic symbol: IV, 2. 3″, 2, 2 *Uvaldose*; III, 9, 1, 4 *Iivaarose*[1]	

[1] The ratio *sal: fem* lies strictly on the limit between class III and IV; in both subdivisions of these classes nephelite basalts are richly represented.

2. Basaltoid nephelinite, Wilkitski island, Dr. N. Sahlbom, analyst.

A. Nephelite basanite, Mt. Sverre, Spitsbergen, Prof. Dittrich, analyst.[1]

The deviation of this analysis from those of Arctic basalts as tabulated by Holmes is still more conspicuous than in the case of the Bennet land olivine-trachydolerite. With the young volcanics of Woodbay, Spitsbergen, described by Goldschmidt (l. c.), it agrees in magnesia content dominating over the lime one, thus being richer in mafic minerals; but none of them contains equal quantities of alcalies, particularly of potash, which in combination with low silica excludes every possibility of feldspar formation.

Even in this case the classification of the rock offers some difficulties; the important content of olivine and the low alumina points out a basaltic type, as strenghtened by the magmatic symbol, yet the intratelluric generation of nephelite together with the perofskite (and potash) content without melilite corroborate a nephelinite affinity, with leucititic dash. From all these rocks the described one differs with respect to the magnesia content exceeding the lime, having this mark common with the Mt. Sverre-basanite, from which it can be derived by raising the alkali content. The rock belongs more intimately to the alkali series than any of the Arctic basalts, retaining some of the pecularities of this group: it is an Arctic basaltoid nephelinite, for which the writer once proposed the name „onkilonite“.[2]

The mineral composition as given by the norm offers a close junction to the true one, differing only in details. The figures of Osann significate the rock as belonging to the scarce group, whose

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[1] V. M. Goldschmidt, l. c.

[2] H. Backlund, Bull Acad. Imp. Sc. St. Pétersbourg 1915 p. 307. The early natives of the north-eastern coast of Siberia, near Behrings sound, called „onkilon“, emigrated, conformable to traditions, under the press of new immigrants, to the northern islands in the Arctic ocean. Cf. *F. v. Wrangel,* Reise, II, p. 220. Berlin 1839.

projection in the *a—c—f*-triangle lies on the *a—f* side. The actual composition („mode“) as calculated on base of the analysis and the quantitative estimation given above is tabulated as follows, with the following modifications against the optical statements, namely that 1/ all TiO_2 is forming perofskite (it was supposed, that the magnetite contains small quantities of TiO_2, and that the augite is titaniferous); 2/ that the leucite forms an independent generation in the groundmass and that the composition of nephelite and leucite is an ideal one (no absolute certainty hereupon was given). The overplus of soda over the aequivalent of alumina, after nephelite and analcite (on base of H_2O) calculated, was checked as acmite molecule belonging to the augite; and the olivine: augite proportion was calculated on base of resting $FeO + MgO + MnO$-content, i. e. the hyalosiderite composition of olivine and the remainder of SiO_2.

Minerals	Weight percentage		Volume percentage	
Olivine	22.09	49.81	19.4	46.8
Augite	27.72		27.4	
Nephelite	21.50	37.85	25.0	45.2
Leucite	14.27		17.3	
Analcite	2.08		2.9	
Magnetite	3.41	7.36	2.0	5.0
Perofskite	3.95		3.0	
Apatite	2.73		2.6	
	99.55		99.6	
Specific gravity det.	3.045		—	
„ „ calc.	—		3.042	

A comparison of the figures found by measuring and calculated gives a good concordance; a calculation of the lenads (except analcite) as extremely potash bearing nephelite, with a composition as for instance found in the sodalite-syenite of Kangerdluarsuk (Greenland) by Lorenzen,[1] or produced experimentally by Ch. and

[1] A. Lorenzen, On minerals from sodalite-syenite, Greenland. Min. Mag. *5*. 1883. p. 60.

G. Friedel,[1] and for which kind of nephelite Morozevicz[2] proposed the formula $K_2Na_5Al_5Si_8O_{10}$, gives 32.45 % of it, but displaces the proportion of augite to olivine in favour of the former (45.48 % and 8.03 %), thus giving discrepancies both with the eyepiece estimation and between the specific gravity determined and calculated (lowering the latter). For calculation of specific gravity served the main values given by Rosenbusch.[3]

The figures of chemical composition of the augite calculated (sub 1, below) in the manner indicated above differ from a usual pyroxen composition in high lime content exceeding the sum of MgO + FeO, yet a comparison with augites from analogous rocks rich in lime and soda, as p. ex. the basalt of Rhön (anal. 3),[4] or in lime and potash, as p. ex. the madupite of Pilot Butte, Wyoming (anal. 2),[5] as tabulated below, shows some common features: —

	1	2	3
SiO_2	52.29	50.86	48.24
Al_2O_3	—	—	4.52
Fe_2O_3	7.69	1.19	6.54
FeO	6.06	1.82	3.26
MgO	6.96	17.42	12.91
CaO	23.46	23.32	21.81
Na_2O	3.00	0.76	0.80
K_2O	—	0.42	0.36
H_2O	—	0.31	0.11
TiO_2	—	3.03	1.44
P_2O_5	—	—	0.36
MnO	0.54	—	—
	100.00	99.16	100.35
Spec. gr.	3.4	—	3.402

[1] Ch. et G. Friedel, Action des alcalis et des silicates alcalins sur le mica: production de la nepheline etc. Bull. Soc. Fr. Min. *13.* 1890 p. 131.

[2] J. Morozevicz, Über die chemische Zusammensetzung des Nephelins. Bull. Acad. Sc. Cracovie, Cl. Sc. math. et nat. Octobre 1907, p. 992.

[3] H. Rosenbusch, Mikroskopische Physiographie I. 2. 4th. ed. 1904.

[4] X. Galkin, Chemische Untersuchung einiger Hornblenden u. Augite etc. N. Jahrb. für Min., Beil.-Bd. *29.* 1910. p. 681.

[5] Whitman Cross, Igneous rocks in Wyoming. Amer. Journ. Sc. *4.* 1897. p. 130, W. F. Hillebrand, analyst.

The two rocks analysed from these localities, whose geological history no doubt in time and in cause of volcanicity will be common, differ conspicuously in their mineralogical and chemical composition, the one being a typical alkaline rock, the other apart from the vesicle minerals showing a distinct character of the calc-alkali-series and approaching to a common basalt; only the high alumina content makes such a calc-alkalic affinity at least doubtful. To facilitate an immediate comparison the two analyses are tabulated together as follows:

	1	2
SiO_2	44.43	41.18
Al_2O_3	18.61	11.69
Fe_2O_3	3.48	5.41
FeO	6.62	7.94
MgO	10.14	10.58
CaO	6.78	9.58
Na_2O	2.29	5.88
K_2O	0.92	3.08
H_2O at 110°	1.58	0.11
$H_2O > 110°$	2.44	0.17
CO_2	0.02	none
TiO_2	1.70	2.34
P_2O_5	0.33	1.25
MnO	0.25	0.32
BaO	0.02	0.07
	99.61	99.65
Spec. gr.	2.861	3.045

This contrast is a typical one for the basalts of the Arctic region, as stated by v. Wolff[1] and others, yet in no part, as known to the writer, pronounced in such an extreme manner as in the case in question; the mixed character of the Arctic province was explained by its situation between the Atlantic and Pacific provinces too, being on both sides limited by them. In no part doubting the peculiar character of this province the writer wishes to direct the

[1] F. v. Wolff, Der Vulkanismus. I, pag. 152 (1914).

attention to the possibility of explaining the genesis of the two rocks differing in such a degree but closely connected one with another in space and probably in time too, by progress of cristallisation during the cooling process after the sheme given by Bowen for the silicate rocks in general.[1] The content of mafic minerals, being common and almost of the same kind in both rocks, except small quantities of accessories, can be neglected in the following discussion.

In decreasing the temperature the degree of dissociation of the magma-components diminishes and the cristallisation process can be derived from the ternary system: quartz (SiO_2) — alumosilicate of alkalies lowest in silica (i. e. $Na(K)AlSiO_4$ [nephelite]) — a hypothetical alumosilicate of lime lowest in silica (i. e. $CaAl_2SiO_6$).

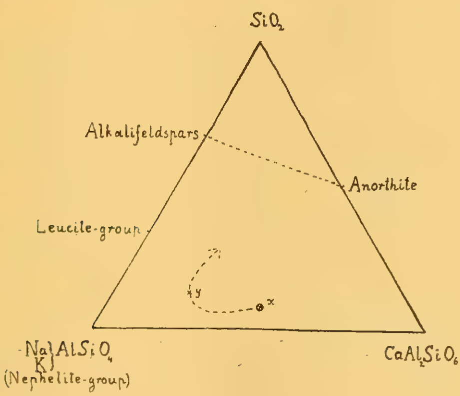

Fig. 1.

Although the pecularities of this system are not yet known, the way of crystallisation of a solution, whose composition lies near the base of fig. 1 in x, can in some measure be foreseen. In an early stage of crystallisation the lenads will begin to separate, but after the bulk of mafic minerals crystallised out and the rest solution acidified, the lenads become instable and due to resorption; the

[1] N. L. Bowen, in Journal of Geology, Suppl. to vol. *23*. 1915.

feldspars begin to separate following the decreasing lime content. If the magma is steam-overladen, the bulk of alkalies from the resorbed lenads can be redissolved during the uninterrupted epimagmatic and postmagmatic flux-rising stage of the rock-development immediately pursuing the magmatic one; and then deposited in the steam cavities or elsewhere as amygdale minerals. In this manner the rock loses her primary or secondary alkalic character and becomes an ordinary basalt, if the cooling was not going too fast and steam or gas was not wanting. If in exchange the cooling was going faster and the mineral separation was interrupted by quenching in some part y of the hypothetic curve figured as appendix to x, the lenadic mineral composition may be fixed and consists of minerals in some regard instable.[1]

The two cases are realised by a rock body of moderate dimensions intruded on a gentle depth in a sedimentary series of at least some permeability to gases; and by a rock of surface-extrusion or in general of quick cooling. The basaltoid nephelinite shows all signs of surface extrusion, while the Bennet-land trachydolerite gives by her coarser grain and the local circumstances some signs of an intrusive sheet. These two examples do not imply an exceptional primary alkaline character of the magma, contrarily a slight one; but they give an explanation of the sporadic alkaline character of the Arctic basalts and this explanation can be extended to the young volcanics of Spitsbergen.

B. Basalt from the nearest east.

The geological features of the volcanics of the Petchora plain are related in a former chapter (p. 16). The petrological character of this basalt is to be described.

[1] The raising steam content to the end of crystallisation probably gives such a direction to the crystallisation way, and the true end of this curve is signified by particular redissolution of the feldspars, the latter being broken down and giving place to the zeolite formation as early as in epimagmatic stage.

It is a dense rock, black in colour, only a few specimens representing minute phenocrystals of plagioclase. The densest rock shows irregularly dispersed smooth valled cavities, empty on the air exposed rock surface, but containing a whole individual of calcite only a few millimetres beneath the surface; and only one centimetre or two deeper these calcite individuals are replaced by black sphaerules, which easily detach from the smooth walls of the cavity. Typical vesicular surface rocks are not represented.

The mineral composition is a simple one. The densest rock is rich in yellowish-brown glass, but the grained ones also contain important quantities of it.

The grained rock consist of albite-twinned microphenocrystals of plagioclase corresponding to labradorite, with a feeble zonar structure; the measurements gave an anorthite content lying between the extremes of 43 % and 70 %, the greater part indicating narrower limits: 56 % and 60 % An. The needle-formed microlithes of the groundmass generation were determined as corresponding to $Ab_{51}An_{49}$, the limits being an anorthite content of 43 and 55 %. The contours of the microphenocrystals are sharp whilst the outlines of the microlithes often are rough. These feldspars are dispersed in the brownish glass without visible order or fluctuation arrangement. — A yellowish augite appears also in two generations, the microphenocrystals showing distinct prismatic forms corresponding to (100) (010) (110), terminations (001) and (111), and twins after (100), or radiating groups with centrifugal growth, or irregular intergrowths, in some degree influencing the feldspar growth. The optical properties as follows:

$c : \gamma = 42°$

$\gamma - \beta = 0.022[6]$

$2 V_\gamma = 43°$, with axial plane in (010);

axial dispersion around $\gamma : A - \varrho \leqq v$

$B - \varrho > v$

indicate some enstatite-augitic affinity,[1] thus FeO and MgO dominating over CaO. A feeble zonal structure with decreasing axial angle and birefraction to the centre, and a faint pleochroism in yellowish and greenish tints strengthen this affinity, as dropformed glassy inclusions too, arranged in files parallel to (001). The second-generation-augites are only occasionally developed as minute grains, between crossed nicols on the black ground appearing as lighting points, who increase in importance and dimensions with decreasing glass content. In the greater part of the specimens the second generation of augite is oppressed. — The olivine is apparently crystallized only in the grained rocks, in which the glass is less abundant, and even here it is subordinate, appearing as small rounded grains, mostly pseudomorphosed to a brownish-red, pleochroic and fibrous aggregate of ironbearing serpentine (?), optically negative and with relatively high birefraction, and to a reddish-brown isotropic mass, perhaps due to resorption. The grains are rounded and of small size and apparently crystallized after the first appearance of augite; in the glassy rock it is quite wanting. — Apatite in small and scarce needles was detected only in rocks poor in glass, where the ore mineral is well individualized as sharp octahedrons of magnetite. In the glassy rock the magnetite forms dendritic skeleton crystals of minute size contributing to the dark colour of the glass.

Besides the inclusions of sedimentary rocks mentioned above (p. 17) the basalt contains great allogenic fragments of a polysynthetical twinned albite-oligoclase (12 % An), and of a greenish diopside of somewhat divergent optical properties ($2V\gamma = 56°$).

The sphaerules are yellow to dark brown transparent in sections. The smaller ones are isotropic, but in the greater ones they develop radiating structure with birefracting radii, optically negative; this birefraction seems to be in close connection with the progress of

[1] W. Wahl, Die Enstatitaugite. Tschermaks Min. u. Petrogr. Mitteilungen. 1907. 26 p. 1—131.

drying of the sphaerule: concentric shrinking cracks appear on them. The glassy groundmass of the rock often seems to change into a substance of similar character, partially when presenting greater masses, also with sensible birefraction and within a greater scale of colours. On the other hand, the glass changes apparently in an other substance too, having some community with the serpentine substance mentioned above; this alteration process is characterized by more greenish tints. — The matter of the sphaerules presents some resemblance to the „hullite", and is described by various authors under different names; it does accompany basalt and diabase flows of several types.[1] Around the sphaerule cavities tangentially placed feldspars form a complete circle.

A specimen of this rock relatively poor in glass and abandoned by sphaerules was analysed with the following results:

	3	A	Molecular num-bers	Molecular per-cent.	3. Mineral composition („Norm")	Figures of Osann
SiO_2	51.60	49.12	0.860	57.26	*Q* 2.70	*s* ...57.9
Al_2O_3	14.89	13.82	0.146	9.72	*Or* 8.34	*A*... 8.0
Fe_2O_3	4.32	6.76	0.026	10.32	*Ab* ....23.58 *F*..55.83	*C*...11.5
FeO	9.50	12.53	0.132		*An* 23.91	*F*...22.7
MgO	6.09	3.19	0.152	10.12	Σ*sal* 58.53	*n*... 7.2
CaO	6.77	8.70	0.120	7.99		*a*... 3.8
Na_2O	2.78	2.49	0.045	2.99	*Di* $CaSiO_3$ ... 4.06	*c*... 5.5
K_2O	1.39	1.26	0.015	1.00	$MgSiO_3$ ... 4.06 *P*..31.93	*f*...10.7
H_2O at 110°	0.87	0.78	—	—	*Hy* $MgSiO_3$ ...11.14	*k*... 0.6
$H_2O > 110°$	1.33		—	—	$FeSiO_3$....12.67	*M*.. 2.26
TiO_2	0.70	0.80	0.009	0.60	*Mt* .... 6.26 *M*.. 7.63	
P_2O_5	0.03	—	—	—	*Il* 1.37	
MnO	—	0.08	—	—	Σ*fem* 39.56	
					P_2O_5 .... 0.03	
					H_2O 2.20	
	100.27	99.53		100.00	100.09	
					Magmatic symbol: III, 5, 3, 4	
					Camptonose	

[1] A chemical analysis of the isolated sphaerules confirms the closeness of them to „hullite" as shown by the comparison tabulated as below: (next page)

3. Basalt, Adzva river. H. Backlund, analyst.
A. „ King Charles land, Spitsbergen. Dr. N. Sahlbom, analyst.[1]

No volumetrical determination of the mineral constituents was undertaken, because the amount of glass varies from place to place in the same specimen, and no supports of a uniform composition of the glass are offered: the fluctuating content of magnetite skeletons in the glass residue seems to corroborate this supposition.

A comparison of the two analyses tabulated above (3 and A) shows the close resemblance of them; they belong both to the camptonose subrang, contain nearly equally high quantities of MgO + FeO and are both characterized by a pyroxene of the enstatite-augite-group, this constituent being extremely well developed in the basalt of King Charles land and the olivine mineral being completely resorbed,[2] whilst in the Adzva rock the more glassy consolidation interrupted a development in the same direction. This resemblance seems to be in no part an accidental one, but seeks

	I	II
SiO_2	39.55	38.59
Al_2O_3	17.20	17.34
Fe_2O_3	2.41	15.97
FeO	6.39	
MgO	8.00	8.65
CaO	2.24	3.94
Na_2O	0.37	none?
K_2O	0.19	0.67
H_2O at 110°	15.87	8.04
$H_2O > 110°$	7.03	13.48
TiO_2	0.18	not det.
MnO	not det.	1.56
	99.44	100.20

I. Sphaerules from the basalt. H. Backlund, analyst.
II. Hullite from the Kinkell-basalt, Scotland. Heddle, analyst. (Transact. Edinb. Roy. Soc. 1879. *29.* p. 89.)

[1] A. Hamberg, Die Basalte des König Karls Landes. Geol. Fören. i Stockholm Förh. 1899. *21.* p. 509.

[2] H. Backlund, Über einige Diabase aus arktischem Gebiet. Tscherm. Min. u. Petr. Mitt. 1907. *26.* p. 378.

her origin probably in a similar geological history of these parts of the Petchora plain in the sense of Suess (cf. p. 16); and a further consequence is a close concordance in time of eruption of both rocks. — Already Holmes fixed the basalts of King Charles and as being a link of the Arctic ones from a chemical standpoin t, and the writer once raised (l. c.) their common character with the diabases of Eastern Spitsbergen in large content of enstatite-augite; perhaps the age of their extrusion is somewhat later than the last mentioned, thus the low content of titanium dioxide do be constant from King Charles land to the Petchora plain and lower than in the older Spitsbergen rocks, lower than in the arctic basalts in general. No alkaline affinity seems to appear in this western part of the eastern plateau-half.

5. MODE OF EXTRUSION OF THE EASTERN BASALTS.

While the greater part of the Atlantic half of the Arctic plateau is buried beneath the sea, in consequence inaccessible to detailed investigations upon the mechanics of extrusion and not suitable to critical comparisons from locality to locality the geological fate of the parts being too variegated in their conditions, contrarily the Siberian half exposes a vaste land-surface, which in her central part since proterozoic time has undergone no folding processes and the-efore may offer very uniform conditions with respect to magma-extrusions.

It is true that the part of the vaste plateau lying north off the Angara (Upper Tunguska) river is a difficult task to investigate and the general exploring ways follow the heading stream valleys, thus often giving a wrong idea of the geological structure of the tract between them. The beginning systematic geological mapping on the southern part of the area (Meister) affirms this statement, for

the capping basalts in this part have a much lesser spreading than may be concluded from the sections on the Angara river, asides from the principal valleys the basalt failing quite.

The points of outburst of the basalts are unknown. The ancient „volcanoes“ pointed out in the upper Lena river region (by Guerassimoff a. o.) play a subordinate role and have not any importance upon the wider distribution of the basalts being local short-lived outbreak-points of lava without considerable tuff production.

A closer examination[1] of the basalt-lined valleys of the north reveals at irregular intervals oblique or vertical offsets of basalt dikes of different thickness, which do not in general produce any greater disturbance in the horizontal strata than a local upbending, occasionally with included greater rock fragments; on both sides of such an upbending the strata redeem their original position at a short distance from the dike without any relative displacement being visible. These fissures seem to have no greater connection with structural lines in general and they get lost in the vaste bordering plateau land without any sign of volcanic action except the related one on both sides of the river bed, at some height from from the bottom and at some distance downstreams. This statement is valid for broader valleys of greater age. On the tributary valleys of lesser importance and greater youth the basalts fail and the cañon-shape disappears. If the offsets of basalt are arranged closer together, the basalt beds corresponding each to an offset join building up a uniform formation of constant level, without visible discordance, and line the cañon-shaped valley on both sides. If, in exchange, the offsets are distant each from the other, the tracks of volcanic action are less significant, the belonging basalt bed rests within small dimensions and is often eroded away, leaving a basaltic tres-

[1] The following statements are in general based upon observations made by the writer during several crossings of the plateau north off the Lower Tunguska river (cf. H. Backlund, „La Géographie“ 1907. Paris) and upon studies of travel-reports (Maack, Czekanowski, F. Müller a. o.).

hold on the bottom of the river bed and sometimes small basalt cliffs on one or on both sides of the valley.

The outbreaks are thus fissural ones, tuffs and volcanic agglomerates are not quite wanting, but they are scarce and saved from erosion only on several points of smaller importance by reasons of conditions related below. It may be supposed strange, that basalt beds of such a mightiness may influence the sedimentary series to such a small degree, but even in center points of basalt development the bordering palaeozoic strata are by no means, if at all, dislocated in such a degree as would be expected by a single outbreak of these dimensions: the strata on both sides of such a mighty „basalt stream“ correspond roughly each to the other stratigraphically and in relative height.

A travel through these countries along the principal rivers — the only ways of communication in summer time — crossing miles after miles central areas of basalt development leaves the impression of a uniform basalt plateau, due to one or several concordant lava flows of important mightiness, without any eminent physiographical peculiarities; in retiring from the central areas the river erosion eats through the lava cap and the floor rock appears in undisturbed position; the lava bed thins out, but always crowns the upper edge of the valley and the valley broadens immediately. A cross section through such a valley with uniform basaltic slopes reveals behind the upper edge an ideal plateau of almost absolute horizontality, strewn with lichen-covered heavy rock-débris; the basalt persists only in the immediate vicinity of the upper edge and then sedimentary rocks of the main palaeozoic type replaces it. The boundary line between basalt and palaeozoic limestone (marked by a different flora of lichens) runs roughly parallel with the main valley. In places, the basalt edge continues outward to a narrower or broader horizontal plateform, from which a gentle slope leads up to the true plateau. The mentioned boundary runs then at the base of this slope; the contact line, even here covered with rock-débris, is more

easily visible and its conformity with the valley direction is not difficult to establish. This matter of fact may awake the thought, that the basalt streams follow ancient river beds, the rapid broadening of the valley downstream immediately out of the basalt region giving some support to this thought. The parts of the valley cut in the basalt are in some sense antecedent.

If the thought developed above were true, the deepseated broad cañon-shaped valleys may have been cut down through the basalt measuring in some parts 300 metres and more of thickness, that being the depth of some valleys and such a mighty outfilling of the valley might seem improbable. The question arises, why did the river course not change passing in the casing, less resistant calcareous sediments?

Previous explorers have certainly reported that the basalt series were composed of a number of separate flows, crowded one upon another with astonishing regularity and of various thickness; that it often happens, that the crowning flow is accompanied in lower level by a parallel intrusion sheet (or sill) of constant thickness, the vertical distance between the capping basalt-bed and the sheet being almost constant too.[1] The massiveness of the sedimentary series may let such a constancy appear astonishing. The old name „trapp" (= staircase) for siberian basalts suggests also a parting in a number of separate flows. In this case it seems probable that the flows may have poured one upon the other, the lowest being the oldest and the topping bed the youngest.

In broader parts of the valleys this partition in mighty flows is well developed and the niveau of each flow persists in horisontality and great constancy, the surface of each of them forming terraces. The shapes of these terraces reminds one from a distance of waterborn raised beaches, and this resemblance leads the thought to updammed lakes with elevated shore lines. The most remarkable fact is that while

[1] An *apparent* geological structure of identical character was tested also by the writer.

the uppermost lava bed is coarse grained, without sensible marks of surface flow, the lowest stream in exchange reveals an amygdaloid structure and a very fine grain, even pumice being occasionally encountered. The evolution of columnar structure too, where encountered, is somewhat paradoxal; on the top of the basalt pile the columnar development is heavy, the individuals being short and of important diameter, whilst the bottom flow sometimes, when ever they have such, exposes exellent groupings of slender pillars and feather-shaped radiating arrangements, which point out an indubitable dependence of the actual surface of the valley bottom, which may consist of basalt or of palaeozoic sediments.

The narrower parts of the valleys, where the detritus cones are swept away, sometimes expose the sedimentary country rock under the top basalt, the floor of the latter being a surface of fluviatil erosion, in some places with waterworn pebbles of sedimentary origin baked together. The sedimentary stripe is by no means the roof of the next basalt horizon below, as may appear from a distance, but the contact plane, apparently almost horizontal, dips really beneath the basalt flow obliquely down to the valley axis, thus representing the slope of the valley in a newer cycle of erosion. This fact, observed in a couple of localities, suggests, that the greater part of intrusive sheets (or sills), related by former explorers, may be only apparent ones,[1] yet really represent extruded basalt flows, which follow the valley bottom at the end of a new cycle of erosion. River pebbles, both of sedimentary and basaltic origin, found somewhere at the base of this second flow and, where exposed, at the bottom of the following one, strengthen this thesis. The basaltfilled valleys expose, in their present stage, an inverted sequence of basalt flows; the oldest flows crown the upper edges of the valleys, while the youngest flows cover the valley floor, apparently forming

[1] The massiveness of the sedimentary strata, without well developed bedding planes, is not favourable to intrusions of such regular sheets or sills.

that the lower permian tillites rest directly over this twice granitized basement.

As was already stated in short, the white granite-syenite intrusions are met with principally in the western parts of the Umango area, outcropping as broader zones in the Sierra de Umango ridge and the Cerro Potrero Viejo. The whole intervening space between the former ridge and the Cerro Cacho is also rich of such dikes. In the last mentioned mountain there are similar dikes too, but a red granite, however, dominates. Only in one part the intrusion of white granite has an abyssal character, viz. in the northern end of the Sierra de Umango ridge. Generally the granite bands are folded together with the limestone banks without crushing, and this circumstance makes it evident, that the intrusion was *contemporaneous* with the tangential pressure.

The folding and the banding are also phenomena characterizing the appearance of the white granite-syenite. To the east, in the region of the Famatina batholith there are no signs of lateral stress, and a *younger granite seems to be lacking there too.* Bodenbender mentions no occurrence of this intrusive from there, and as to myself, I have never discovered any dikes of this rock inside the batholith.

Nothing further are known regarding the occurrences of younger (post-Famatina) granites in the pampean sierras-area, because the study of the chronology of the old intrusions in this area is still a task never touched upon. According to a verbal communication by Rassmuss, he has seen traces of a younger intrusion in the Sierra de Velazco, a white granite crossing the red one, the latter corresponding to the Famatina granite.

a) MANNER OF INTRUSION OF YOUNGER GRANITES AND SYENITES.

As already stated, the younger intrusives show a less conspicuous abyssal character than the Famatina red granite, and they depend to a considerable degree in their manner of intrusion on the struc-

tural planes of the schist mass. Crosscutting dikes are occassionally seen, but more irregular bodies with sinuous contacts and numerous apophyses are not met with. Brecciation, melting and assimilation are also odd phenomena, except a certain class of banding, where a lateral assimilation on a very reduced scale has succeeded. The whole appearance of the intrusion depended apparently upon a lateral controlling pressure, causing the mentioned *parallel* injections along the planes of weakness. The areal extension of the resulting *banded rocks* is a very considerable one. Although they are of the same origin as many common parallel arterites in archaean terranes, the banding in the Umango area shows a somewhat different character, due to an already mentioned lateral assimilation along the granite veins. The lateral assimilation is common especially where the granite intrudes amphibolite schists, from which results a product of intermediary composition. This last *is also banded,* evidently a result of parallel movements under stress conditions. Also at the borders of other schists such a banding was produced.

The banding phenomenon has been studied already long time ago in different archaean terranes. The following two classes may be distinguished: 1) Banding produced by flowing in a primary magma with the formation of *„Schlieren“* or streaks of different composition. The well known banded gabbro of Skye, Scotland, described by Geikie and Teall[1] belongs to this type. 2) Banding produced by the injection of magma along the structural planes of a schist mass. This type is the more important one and is *of regional extension,* as is shown by investigations in many parts of the world.[2]

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[1] A. Geikie and J. J. H. Teall: Banded Igneous Rocks of Skye. Quarterly Journal of the Geological Society of London. Vol. L. 1894.

[2] J. J. Sederholm: Om granit och gneis. Bull. Comm. Géol. de Finlande. N:o 23. Helsingfors 1907.

P. J. Holmquist: Zur Petrographie und Geologie von Ornö Hufvud. Bull. Geol. Inst. of Upsala. Vol. X. 1910.

Adams and Barlow: Geol. of the Haliburton and Bancroft Areas, pro-

quence of the basalt outbreak period and geological incidents to be related below a capturing of river heads on a large scale took place, partly changing the main drainage in general and completely changing it in details. Thus this ribbon of mesozoic deposits represents an ancient river course (with affluents) of mesozoic age, which drained the central-asiatic mesozoic (Angara)-continent.

From the top of the main plateau (e. g. from a point at 68° N and 102° E) there are often seen, generally in the direction of lessened basaltic action, smaller isolated table mountains, which seem to surpass in height the surroundings. They are crowned by a basalt cap and the slopes are completely covered with basalt-débris, which do not permit any conclusion upon the base of the roofing basalt.[1] The connection of the basalt with the main flows is uncertain. On the slopes, but never on the top-basalt of these table mountains there were encountered waterworn pebbles of palaeozoic rocks, which in this strange company and at this exposed point lead the thought to glacialdrifted erratics, no other vestiges of glaciation being recorded. A development step by step of the perception reported above forces to analogical conclusions with respect to these table mountains too, that they represent the bottom of ancient river courses, perhaps affluents to the main system, filled out by a basalt flow; the sedimentary rocks served as frame. In sequence the lesser resistant country rock of the frame was strongly denuded and the more resistant basalt flow was brought into relief by its greater resistance to the denudation agents; the pebbles thus derive from underneath the basalt cap. The landscape was morphologically inverted. This statement affirms that far from all water courses, even principal ones at the present time, have persisted as such from mesozoic time, and that in many cases, when the valleys were filled out by basalts, the river courses eroded a new bed sideways of the old basaltfilled valley, no „valley-in-valley“-structure having been developed.

[1] „Witnesses of erosion“.

Much has been written about the contemporaneousness of these basalts. Suess (l. c.) states, that while some flows crown the upper edge of the valleys, others have run down along the bottom; from this he concludes, that they are not contemporaneous in a stronger sense, but owe their outbreak to a uniform geological process. Of this process he makes no decisive statement, yet he enumerates with conscientiousness the presumptive „volcanoes", or centres of eruption, and mentions the possibility of fissural one.

On base of the statements above it is possible to give a picture of the mode of extrusion of the basalts confirming the uniformity of the connected geological process as follows. Towards the end of the Angara-time the continent being almost completely base-levelled began to rise. The river erosion immediately reinforced began to cut down deep valleys, a stagnation of the rise contributed to a development of broad river plains whither the flora migrated down, whilst the capping younger sediments of the uplifted area began to be eroded away.

At that stage the first basalt lava breaks out from fissures, which seem to set up from downward, under an upward pressure, and these fissures meeting on their way through the uniform sediment plateau the deep-seated valleys open and pour out a portion of lava, but seem never to reach the main surface, or if so, the immediate output of basalt in the valley seems to hold the main lava surface on a level under the main plateau surface. If the flow was uniform, the river keeps back its original course and the erosion is reinforced anew, because an increasing rise, besides the uplift of the river bed by the basalt layer, immediately succeeds the basalt eruption, continues during the accelerated throughcutting of the basalt and of the floorrock and dies away by forming a new but somewhat smaller river plain. Then the process is repeated with alternating basalt outbreaks and maxima and minima of uplift.

Not everywhere the maximum of upheaval seems to be equal. Yet the maxima of upheaval do by no means coincide with the

maxima of volcanicity, the latter being in high degree dependent on the depth and number of the dissecting valleys. Comparing the absolute heights of the plateau, and combining them with the mightiness of the basalt piles and with the number of separate flows a line may be drawn, which runs from the upper Piasina region in the north to the Tunkin Alps in the south and which may in general correspond to an axis of the greatest upheaval (fig. 2). This axis of the greatest upheaval coincides to a great extent with the ancient valley depicted above and hence the great development of volcanicity along this line may be explicable.

Fig. 2.

As to the cause of these upheavals the thought of *isostatic readjustment* lies at hand. Yet there is no distinct region of subsidence in the neighbourhood, that could be taken into consideration as a compensating area, the nearest lying too far away and being separated from the plateau described above by broader zones of tectonical weakness. Moreover the uniformity and the flatness of the (northern) area does not favour such a strong and accelerated denudation, as may be expected in areas of uplift. In all, *a rhythmical uplift, at well defined intervals, may hardly find its explication in isostatic readjustment alone.*

De Geer discussed the late tertiary uplift of Scandinavia and pointed out, that in one third the border of the region of upheaval is accompanied by basaltic eruptions, which were pressed up by the downwarping of the adjacent sea-bottom,[1] by manner of hydrostatic pressure; in sequence the eruption channels were stopped up and the pressure transplanted to the main backland resulting in an increasing upheaval. In the case of the eastern half of the Arctic plateau, the magmatic action beneath the plateau seems to be a more active one than was to be expected by simple isostatic eadjustment, and perhaps reactions and movements in the asthenosphere,[2] as suggested by Ampferer,[3] may be the true cause of the vertical crust-movements in the case considered.

In consequence of the statements above, the basalt-marked line, which crosses the lower Khatanga, Anabar and Olenek rivers and almost points out the boundary between palaeozoic and mesozoic marine sediments, represents a step fault as described by the writer before,[4] but characterized by upheaval of the southern wing, not by downwarping of the northern one. The volcanics of this line are not yet sufficiently known, but seem to be of a more variegated kind.

6. CONCLUSIONS.

The eastern half of the Arctic basalt plateau is characterized by volcanics representing the mixed features of the arctic petrographical province; in general, they agree well with the western ones, showing almost a constant and uniform composition over great areas, and then accidentally acquiring pronounced signs of an alkaline affinity, and developing a greater variety of rocks.

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[1] G. De Geer, Kontinentale Niveauveränderungen im Norden Europas. Pet. Mitt. 1912. II.

[2] A. Holmes, Radioactivity and the earths thermal history. Geol. Mag. 1916, p. 267.

[3] O. Ampferer, Über das Bewegungsbild in Faltengebirgen. Jahrb. geol. Reichsanstalt Wien. 1906. *56*, p. 606 et seq.

[4] H. Backlund, „La Géographic“ l. c.

The alternating eruption took place during a distinct period of rhythmical continental upheaval in such a close alliance the former with the latter, that it is difficult to separate the cause from the effect. The mode of eruption, being a fissural one, points toward a deeper magmatic action as the cause of upheaval and eruptivity; the fissures, which generally do not represent faulting lines, were opened from downward by upward pressure, and, meeting on their way upward stripes of pronounced weakness formed by ancient deepseated valleys, they do not reach the main plateau surface, at least not by their volcanicity; the latter finds its outlet in pouring down the valleys. The plateau behaves as a uniform block, and the uniformity of volcanics seems to stay in connection with this behaviour. In places where the fissures develop into veritable faulting lines, with differential and opposed movements on both sides of the line, the volcanics seem to become more variegated, specially in cases where the faults are manyfold and the blocks between them become tilted (New Siberian Islands with Bennet Island).[1]

It is to be controlled if this statement is to be valid for the Atlantic half. Few significations may satisfy.

De Geer states, in his memoir upon the physiography of Spitsbergen,[2] that a zone of diabasic eruptions trends „from SE to NW as a diagonal through the region of the present Ice Fjord, separating the main fjord from the diverging four inner branches“. The diabases are very uniform ones, and this zone marks a distinct flexure of upheaval. The Stor-fjord line of diabases, running in

[1] From the standpoint developed above even simple faults, accompanied by differential movements and volcanic action, may, in consequence, depend upon movements and actions of a different kind in the subcrustal magma (asthenosphere) as compared with the upward movements beneath the plateau; and concluding from uniformity of force to homogeneity of acting material the logic compels one to suppose a diversity of deepseated material in connection with irregular movements; thus the alkaline character of rocks seems by no means to be obliged to assimilation of country rocks, but can appear independent.

[2] G. De Geer, On the physiographical evolution of Spitsbergen. Geografiska Annaler 1919. *2.* pag. 164 (Stockholm).

N-S direction along the eastern shore of the fjord, marks also a zone of upheaval and the basalts (diabases) are confined to transversal fissures; the northern straits (Hinlopen and farther north) are areas of distinct upheaval.

Reck, in his large monograph on icelandic mass-eruptions,[1] tries in vain to prove the „horst"-origin of the steep, vertical-sided tabular mountains of minute square area (Herdubreid a. o.), the whole resting area around them being broken down by faults. The thesis appears so improbable, that the author himself does not believe it: their origin by upheaval is quite sure. In all, the faulting processes related from Iceland must undergo a new control from the standpoint of discernment between movements of upheaval and subsidence, for if all subsidences related from Iceland were true ones, there would not remain much of it over the sea level.

The consequence of the views developed in course of the present notice is, that volcanics, as once raised by the theory of v. Buch and his followers, may be more active than is admitted even by Gilbert in his laccolith-theory, the degree of moving forces lying somewhere between both ones.

Geological Institution of the Academy of Åbo. May 1920.

[1] H. Reck, Isländische Masseneruptionen. Geol. u. palaeontolog. Abhandl. herausgegeb. von E. Koken. N. F. IX. 1910. H. 2, pag. 30 a. o.

ACTA ACADEMIAE ABOENSIS
MATHEMATICA ET PHYSICA I:3

ÜBER EINE DURCH EIN DREIDIMENSIONALES RESONATORENSYSTEM ERZEUGTE INTERFERENZ DER ELEKTROMAGNETISCHEN WELLEN

VON

D:R KARL F. LINDMAN
PROFESSOR DER PHYSIK AN DER AKADEMIE ÅBO

ÅBO AKADEMI
ÅBO 1921

ÅBO 1921
ÅBO TRYCKERI OCH TIDNINGS AKTIEBOLAG

INHALT:

I. EINLEITUNG.

1. Als ich im Winter 1909—1910 im physikalischen Institut der Universität Helsingfors mit Untersuchungen über das selektive Absorptions- und Reflexionsvermögen elektrischer Resonatorensysteme[1] beschäftigt war, benutzte ich bei einigen Versuchen dreidimensionale Gitter (Raumgitter), die aus mehreren zueinander parallelen, äquidistanten ebenen Gittern bestanden. Als Elemente der Gitter dienten ringförmig gebogene Metalldrähte von derselben Eigenschwingungsperiode, welche in horizontalen bezw. vertikalen Reihen angeordnet waren und von dünnen aus Pappe verfertigten Leisten getragen wurden. Beim Messen der Schwächung, welche die mit den Eigenschwingungen der Gitterelemente angenähert isokronen elektromagnetischen (Hertz'schen) Wellen beim Durchgang durch ein solches Raumgitter erlitten, beobachtete ich gelegentlich, dass die durchgelassene Strahlungsintensität sich sogar verringern konnte, wenn jedes zweite der aufeinander folgenden ebenen Gitter entfernt wurde, und nach Einschaltung dieser Gitter sich wieder vergrösserte. Es handelte sich hier offenbar um eine von den an den verschiedenen Netzebenen reflektieren Wellen erzeugte Interferenzerscheinung. Nach dem Entfernen der zwischenliegenden Gitter näherten sich im der Tat die Abstände zwischen den an ihren Plätzen gebliebenen ebenen Gittern der halben Wellenlänge der senkrecht einfallenden Schwin-

[1] Die Ergebnisse dieser Untersuchungen sind niedergelegt in meiner Abhandlung „Über das selektive Absorptions- und Reflexionsvermögen elektrischer Resonatorensysteme" (Öfversigt af Finska Vetenskaps-Societetens Förhandlingar, LII, 1909—1910, A, N:o 10).

gungen, so dass die an diesen ebenen Gittern reflektierten Wellen sich dann durch Interferenz verstärkten, welches — trotz der geringeren Anzahl von Netzebenen bezw. Gitterelementen — eine vergrösserte Schwächung der durchgehenden Strahlung zur Folge hatte.

Da der Zweck der erwähnten Untersuchungen ein anderer war, untersuchte ich damals diese Interferenzerscheinung nicht näher. Irgend welche Beobachtungen über Interferenzerscheinungen bei Raumgittern dürften auch kaum früher gemacht worden sein. Zwei Jahre später (1912) folgte indessen die berühmte Laue'sche Entdeckung der durch die Atomgitter der Kristalle erzeugten Interferenz der Röntgenstrahlen.

Da nun die Hertz'schen Wellen — trotz ihner enorm viel grösseren Länge — mit Bezug auf ihren impulsartigen Charakter eine gewisse Analogie mit den Röntgenstrahlen zeigen und die Bragg'sche Interprätierung[1] des Laueeffektes sich auf der Annahme der Existenz äquidistanter ebener Atomschichten in den Kristallen gründet, an denen die Röntgenstrahlen reflektiert werden, scheint es nicht ohne Interesse, die oben erwähnte durch dreidimensionale Resonatorensysteme erzeugte Interferenz der Hertz'schen Wellen etwas näher zu untersuchen, zumal da ein elektromagnetisches Analogon zu der Röntgenstrahlinterferenz in Kristallen dadurch eventuell erhalten werden könnte. Eine solche Untersuchung hatte ich schon vor vielen Jahren geplant, obwohl ich wegen anderer wissenschaftlicher Arbeiten und verschiedener dazwischen gekommener Hindernisse sie erst jetzt zur Ausführung bringen konnte.[2] Die Ergebnisse meiner diesbezüglichen Versuche werden in dem vorliegenden Aufsatze mitgeteilt.

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[1] W. L. Bragg, Nature *90,* 410 (1912); Proc. Cambr. Phil. Soc. *17,* 43—57 (1913).

[2] Nach meiner Übersiedelung nach Åbo (im Jahre 1918) zeigte es sich, dass der Grundboden des Gebäudes, wo das physikalische Institut der hiesigen Akademie eingerichtet wurde, so instabil war, dass sogar die Julius'sche Aufhängevorrichtung eine erschütterungsfreie Aufstellung der von mir benutzten Spiegelgalvanometer nicht ermöglichte. Erst nachdem das Institut vor kurzem ein Annex in einem anderen Teil der Stadt erhielt, konnten die Messungen dort ausgeführt werden.

Da im Folgenden Hinweise auf die Untersuchungen der Herren Bragg[1] öfters gemacht werden, scheint es dienlich, die beiden fundamentalen Gesetze hier anzuführen, die von diesen Forschern für die Reflexion der Röntgenstrahlen an Kristallen zunächst aufgestellt wurden:

1. Einfallswinkel = Reflexionswinkel.

2. Wenn homogene („monokromatische") Röntgenstrahlen auf die Kristallfläche einfallen, erreicht die reflektierte Intensität nur für singuläre Einfallswinkel (i) merkliche Werte und zwar lassen sich diese Winkel durch die Formel

$$2\,d \cos i = n\,\lambda$$

darstellen, worin n relativ kleine positive ganze Zahlen (die Ordnungsnummern der Reflexe), d und λ Konstanten sind. Nach der Bragg'schen Theorie bedeutet d den Abstand zwischen den zur Oberfläche parallelen äquidistanten und mit Atomen in gleicher Weise besetzten Netzebenen im Kristalle, während λ sich als die Wellenlänge der Röntgenstrahlen herausgestellt hat. Anstatt des Einfallswinkels (i) bedienen sich die Herren Bragg gewöhnlich des Neigungswinkels („glancing angle") zwischen den einfallenden Strahlen und der Kristallfläche (bezw. den Netzebenen im Kristalle). Nennt man diesen Winkel $\varphi\,(= 90° - i)$, so geht die obige Formel über in

$$2\,d \sin \varphi = n\,\lambda.$$

II. APPARATE.

2. Erreger, Empfänger (geradliniger Sekundärleiter mit Thermoelement) und Messungsmethode (gleichzeitiges Ablesen eines Broca'schen und eines du Bois-Ruben'schen Spiegelgalvanometers) waren dieselben, welche ich bei meinen in Helsingfors über elektrische

[1] Eine zusammenfassende Darstellung dieser Untersuchungen findet man in der Arbeit: W. H. und W. L. Bragg, X-rays and Crystal Structure. (London 1918).

Wellen ausgeführten Versuchen benutzt hatte.[1] Das Arbeitszimmer hat relativ grosse Dimensionen (Länge etwa 9 m, Breite 5 m, Höhe $3{,}2$ m), so dass Störungen durch Reflexionen an den Wänden und dem Fussboden leicht vermieden werden konnten.

Die Resonatoren, welche die Elemente der zu untersuchenden Gitter bildeten, hatten die Form von nahezu geschlossenen Ringen und bestanden aus 13 cm langen und $0{,}7$ mm dicken kupfernen Drähten. Der Abstand zwischen den Drahtenden betrug 3 à 4 mm. Wie ich in meiner in der Einleitung (S. 5) erwähnten Arbeit festgestellt habe, hat ein ringförmiger, nahezu geschlossener Sekundärleiter von konstantem Querschnitt eine ein wenig grössere Eigenschwingungsperiode als ein geradliniger von derselben Länge und Dicke und zwar nimmt dieser Unterschied zu, wenn man den Abstand zwischen den Enden des ersteren verkleinert. Es erwies sich indessen, dass die halbe Eigenwellenlänge der erwähnten $13{,}0$ cm langen und $0{,}7$ mm dicken ringformigen Resonatoren, deren freie Enden 3 à 4 mm von einander entfernt waren, nur etwa 3 mm länger als die Drahtlänge war (also = etwa $13{,}3$ cm).

Diese ringförmigen Resonatoren waren stets in äquidistanten horizontalen bezw. vertikalen Reihen angeordnet und wurden dabei von aus dünnen Holzleisten gemachten Stativen getragen (fig. 1). Die wagerechten $0{,}5$ cm dicken Leisten (von quadratischem Querschnitt) waren mit kleinen hölzernen Haken versehen, an denen die ringförmigen Resonatoren so aufgehängt waren, dass die Öffnung zwischen den Enden jedes Resonatordrahtes in derselben horizontalen Ebene wie der Mittelpunkt des Resonatorkreises lag, wobei die Öffnungen aller Resonatoren nach derselben Seite hin gerichtet waren (Siehe Fig. 1). Es wirkte dann bei vertikaler Stellung des stabförmigen Erregers und bei normaler Inzidenz die elektrische

[1] Siehe K. F. Lindman Öfversigt af Finska Vet. Soc. Förh. LI, 1908—1909, A. N:o 5. — Ann. d. Phys. 38, S. 526 (1912). — Ein Teil dieser Apparate (z. B. das du Bois-Ruben'sche Panzergalvanometer) gehört dem physikalischen Institut der Universität Helsingfors und bin ich Hrn Prof. Hj. Tallqvist für die Erlaubnis, diese Apparate noch in Åbo zu benutzen, zu grossem Dank verbunden.

Kraft der Hertz'schen Wellen auf die Resonatoren. Der Abstand zwischen zwei benachbarten horizontalen bezw. vertikalen Reihen der Aufhängungspunkte (bezw. Mittelpunkte) der Resonatoren betrug 10 cm. Jedes dieser ebenen Resonatorengitter umfasste 7 horizontale und 11 vertikale Reihen und bestand somit aus 77 ringförmigen in derselben Ebene angeordneten Elementen. Das zu untersuchende Raumgitter wurde aus mehreren (gewöhnlich fünf) solchen ebenen hintereinander angeordneten Gittern zusammengestellt. Dieses Raumgitter erhielt dabei die Form eines regelmässigen rechtwinkligen Gitters, in dem die einzelnen Resonatoren sich in den Ecken der parallelepipedförmigen Teile befanden, aus welchen das ganze Gitter zusammengesetzt gedacht werden konnte.

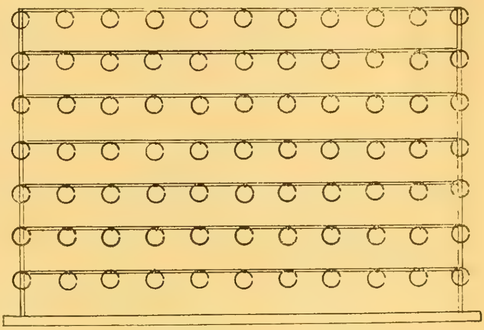
Fig. 1

Wenn ein Element eines einzelnen ebenen Gitters durch einen ringförmigen Messresonator von derselben Periode ersetzt wurde, zeigte es sich, dass die Wirkung auf diesen Messresonator in Gegenwart der anderen Elemente des Gitters etwas grösser war als in Abwesenheit derselben. Bei der erwähnten Verteilungsdichte der Elemente hatten aber die anderen Elemente keinen merkbaren Einfluss auf die Eigenperiode des als Gitterelement benutzten ringförmigen Messresonators. Beim Messen der Wellenlänge nach der Boltzmann'schen Methode mit zwei gegeneinander verschiebbaren ebenen Metallspiegeln ergab sich nämlich für die Wellenlänge derselbe Wert, wenn der Messresonator ein Element des Gitters war, als wenn er isoliert stand. Aus der Gestalt der dabei erhaltenen Interferenzkurven konnte ausserdem geschlossen werden, dass die Dämpfung der Eigenschwingungen der Gitterelemente bei der betreffenden Verteilungsdichte nur unwesentlich grösser war als die der freien Eigenschwingungen dieser (als isoliert gedachten) Elemente.

III. DURCHLÄSSIGKEITSVERSUCHE.

3. Um die Intensität der durch ein Raumgitter gegangenen elektrischen Wellen ihrem absoluten Betrage nach richtig messen zu können, kommt es sehr auf eine richtige Abschirmung der ringsum fallenden Strahlung an, damit die Messungen nicht durch Beugungserscheinungen vereitelt werden sollen. Da die entsprechenden Reflexionsversuche in dieser Beziehung einfacher und zuverlässiger erschienen und sich direkt mit den oben erwähnten Bragg'schen Versuchen vergleichen liessen, beschränkte ich mich jetzt auf einige wenige Durchlässigkeitsversuche, die eigentlich nur eine Wiederholung und Ergänzung meiner früheren in der Einleitung erwähnten diesbezüglichen Beobachtung bezweckten.

Die Versuchsanordnung wird in Fig. 2 schematisch angegeben. Der Oszillator O befand sich in der Brennlinie eines zylindrisch-parabolischen Reflektors, dessen Brennweite gleich $^1/_4$ der Wellenlänge der primären Schwingungen war. An dem Reflektor war ein metallischer Trichter T von quadratischem Querschnitt befestigt, der vorn eine 33 cm $\times$ 33 cm grosse quadratische Öffnung hatte. Der geradlinige mit Thermoelement versehene Resonator I, der sich innerhalb des Trichters in der Nähe seiner Wand und der Öffnung befand, diente als Standardindikator und war deshalb mit dem einen Galvanometer verbunden. Die 5 vertikalen und zueinander parallelen ebenen Gitter G_1, G_2, $\cdot\cdot$ G_5, die zusammen das zu untersuchende Raumgitter bildeten, waren auf einer wagerechten 80 cm breiten Holzscheibe derart montiert, dass der Abstand d zwischen den benachbarten äquidistanten Netzebenen ohne Schwierigkeit variiert werden konnte. Das dem Oszillator O am nächsten stehende Gitter G_1 blieb die ganze Zeit in einer unverändertern Entfernung von O. Wenn ein grosser Metallspiegel unmittelbar vor dem Gitter G_1 aufgestellt wurde, veränderte sich die Wirkung auf den Standardindikator I kaum merkbar. Eine Beeinflussung des Standardindikators

durch die am Resonatorensystem reflektierte Strahlung war also nicht zu befürchten. Der mit zylindrisch-parabolischem Reflektor versehene geradlinige Messresonator *R* stand in unveränderter Lage hinter dem Gittersystem. Eigentlich hätte noch eine Blende zwischen dem Gitter und dem Empfänger angeordnet werden sollen. Für die wenigen vergleichenden Durchlässigkeitsversuche, die ich jetzt vornahm, schien aber eine solche Blende entbehrlich, zumal sie leicht als eine neue Fehlerquelle hätte wirken können. Die mittelsten wagerechten Elementenreihen der Gitter und die Mittelpunkte

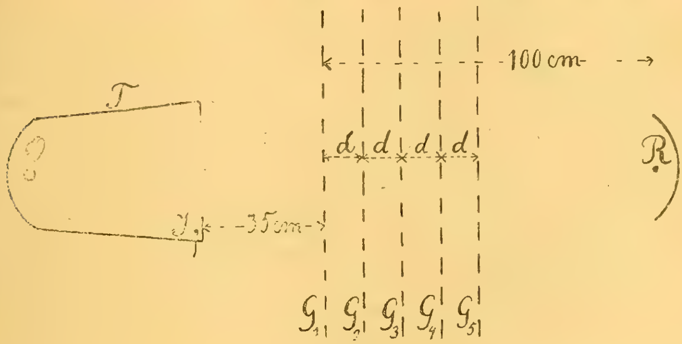

Fig. 2

von *O* und *R* befanden sich etwa 1,3 m. über dem Fussboden des Arbeitszimmers. Die halbe Eigenwellenlänge des Oszillators ($^1/_2\ \lambda_O$) und die des Messresonators ($^1/_2\ \lambda_R$) waren bei diesen Versuchen beide = 13,0 cm und also von fast derselben Grösse wie die der Gitterelemente (13,3 cm).

4. Durch Messung der durchgelassenen Intensität beim Variieren des Netzebenenabstandes *d* erhielt ich die in Fig. 3 dargestellte Intensitätskurve. Jede Messung wurde mehrere Male (mindestens drei aber oft sechs oder sieben mal) wiederholt und aus den so erhaltenen — stehts nahe miteinander übereinstimmenden — Werten das Mittel genommen. Die maximale Ordinate dieser Kurve liegt bei $d = 6{,}9$ cm. Die an zwei benachbarten Netzebenen reflektierten Wellen hatten in diesem Falle einen Gangunterschied von $2 \cdot 6{,}9 = 13{,}8$ cm, der mit der halben Wellenlänge (13 cm) recht

nahe übereinstimmt. Das Maximum der durchgelassenen Intensität erklärt sich demnach durch ein entsprechendes Minimum der reflektierten Intensität. Ebenso findet man, dass das Minimum der durchgelassenen Strahlung (für $d = 13$ cm) einem Maximum der reflektierten Intensität entspricht. *Wenn ein dreidimensionales aus gleichen ringförmigen in parallelen äquidistanten Ebenen angeordneten Elementen bestehendes Resonatorensystem von senkrecht einfallenden, mit den Eigenschwingungen der Gitterelemente angenähert isokronen elektromagnetischen Wellen durchstrahlt wird, so ist also die*

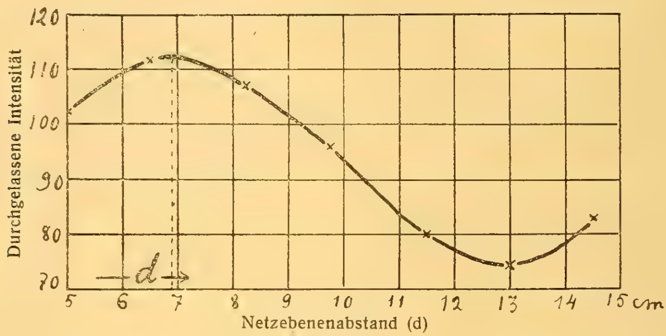

Fig. 3

durchgelassene Intensität am grössten, wenn der Abstand zwischen den benachbarten Netzebenen gleich $^1/_4$ der Wellenlänge ist, und am geringsten, wenn dieser Abstand gleich der halben Wellenlänge ist.

Wenn beim Netzebenenabstande $d = 6{,}5$ cm das zweite und das vierte Gitter (G_2 und G_4 in Fig. 2) entfernt wurden, so dass d jetzt $= 13$ cm (= der halben Wellenlänge) wurde, nahm die durchgelassene Intensität — trotz der Verminderung der Netzebenenanzahl — um etwa 6 Proz. ab. Es war dies eine Bestätigung der von mir schon vor vielen Jahren gemachten Beobachtung, die in der Einleitung (S. 5 u. 6) diskutiert wurde.

IV. REFLEXIONSVERSUCHE.

5. Das vorher benutze aus fünf Netzebenen bestehende Resonatorensystem, dessen Reflexionsvermögen jetzt untersucht werden sollte, wurde vor dem Oszillator *O* (Fig. 4) in etwa 2 m Entfernung von ihm aufgestellt. Der Messresonator *R*, welcher jetzt mit

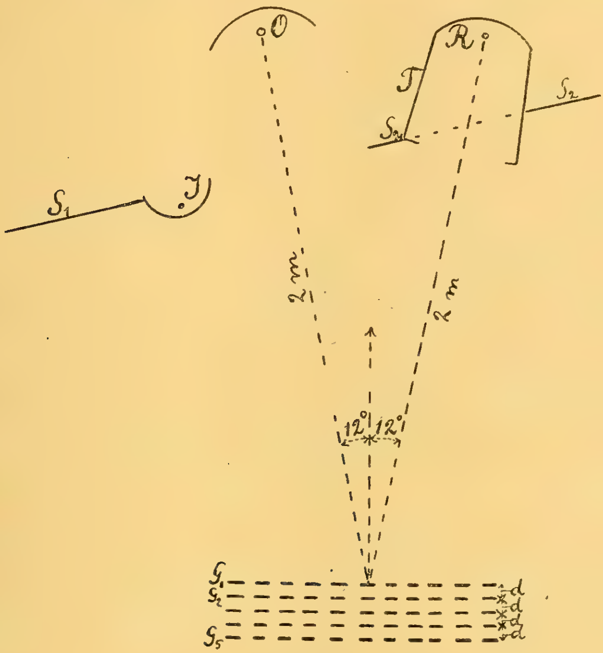

Fig. 4

dem früher (vor dem Erreger) benutzten Trichter *T* versehen war, empfing die am Resonatorensystem reflektierten Strahlen. Der Standardindikator *I* befand sich in der Brennlinie eines hohen zylindrisch-parabolischen Spiegels. Ausser diesem Spiegel dienten die Metallschirme S_1 och S_2 zum Abblenden der seitlichen Strahlen, wie in der Figur angedeutet ist. Die halbe Eigenwellenlänge des Oszillators ($^1/_2\ \lambda_0$) und die des auf ihm abgestimmten Messresona-

tors ($^1/_2\ \lambda_R$) war bei allen Reflexionsversuchen, wie auch bei den obigen Durchlässigkeitsversuchen, = 13,0 cm, welcher Wert also um z:a 0,3 cm kleiner als die halbe Eigenwellenlänge der Gitterelemente war. Diese Differenz, die ich anfangs als unwesentlich betrachtete, war dadurch bedingt, dass nach meinen früheren Versuchen[1] das Gitter diejenigen Wellen bezw. Schwingungskomponenten am stärksten reflektierte, deren Periode ein wenig kleiner als die der Gitterelemente war. In Abwesenkeit des Gitters konnte bei verschiedenen in Frage kommenden Stellungen des Empfängers keine oder fast keine Wirkung auf ihn beobachtet werden (es waren also keine oder fast keine merkbaren Fremdwirkungen vorhanden). Beim Drahen des Gitters um eine durch die Mitte des vordersten Gitters (G_1) gehende vertikale Axe sowohl in der einen wie in den anderen Richtung ziegte es sich, dass die Wirkung auf den Empfänger am grössten war, wenn das primäre Strahlenbündel und das reflektierte, auf den Empfänger fallende mit den Gitterebenen gleich grosse Winkel bildeten. Es wurde dies bei verschiedenen Einfallswinkeln und verschiedenen Netzebenenabständen beobachtet. Für die Reflexion der elektromagnetischen Wellen an dem Resonatorensystem gilt also das gewöhnliche Reflexionsgesetz, nach dem *der Reflexionswinkel gleich dem Einfallswinkel ist.* Es entspricht dies dem ersten in der Einleitung (S. 7) erwähnten Bragg'schen Gesetze für die Reflexion der Röntgenstrahlen an Kristallen.

Durch Drehung des Empfängers um seine zu den reflektierten Strahlen parallele Symmetrieaxe wurde festgestellt, dass die reflektierten Strahlen, gleich wie die einfallenden, geradlinig polarisiert waren und dass die zur Einfallsebene senkrechte Richtung des elektrischen Vektors der einfallen Schwingungen sich durch die Reflexion am Gitter nicht änderte.

6. Bei den unten zunächst beschriebenen Versuchen war der Einfalls- bezw. Reflexionswinkel = 12°. Durch Messung der an dem

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[1] Vgl. die auf S. 5 zitierte Arbeit des Verfassers.

Resonatorensystem reflektierten Strahlungsintensität[1] beim Variieren des Netzebenenabstandes d erhielt ich die in Fig. 5 dargestellte Kurve I, die ein Maximum und ein Minimum der reflektierten Intensität deutlich erkennen lässt. Das Maximum entspricht einer Phasendifferenz zwischen den an den benachbarten Netzebenen reflektierten Strahlen von $2 \cdot 13{,}5 \cos 12^\circ = 26{,}4$ cm, welcher Wert mit

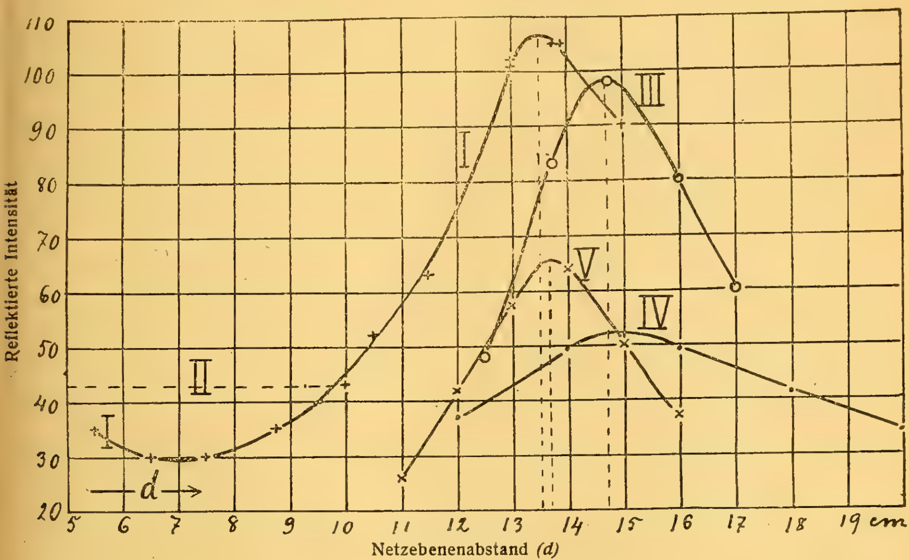

Fig. 5

der Wellenlänge der einfallenden Schwingungen (26,0 cm) sehr nahe übereinstimmt. Das Minimum der Kurve I in Fig. 5 liegt bei $d = 7$ cm. Für die entsprechende Phasendifferenz ergibt sich der Wert $2 \cdot 7 \cos 12^\circ = 13{,}7$ cm, der um 0,7 cm grösser als die halbe Wellenlänge ist. Die Ursache zu dieser geringen Abweichung, von der wir hier absehen, soll später diskutiert werden. Man findet, dass das Maximum und das Minimum der betreffenden Reflexionskurve mit

[1] Jeder fixe Punkt der Intensitätskurve wurde wieder wie bei allen in diesem Aufsatze beschriebenen Versuchen durch mindenstens drei, aber gewöhnlich vier oder fünf (manchmal noch mehr) Ablesungen der beiden gleichzeitigen Ausschläge der Galvanometer bestimmt. Die Quotienten dieser Ausschläge stimmten in jedem Falle mit einander sehr nahe überein.

Bezug auf ihre Lagen dem Minimum bezw. Maximum der Durchlässigkeitskurve sehr genau entsprechen, so dass die aus ihnen ermittelten Werte der Phasendifferenz der an benachbarten Netzebenen reflektierten Wellen fast identisch sind. Die vorhin (S. 12) gegebene Deutung der singulären Punkte der Durchlässigkeitskurve wird also durch die Gestalt der Reflexionskurve I (fig. 5) bestätigt. Dass es sich hier in der Tat um eine Interferenzwirkung zwischen den an den einzelnen Gitterebenen reflektierten Wellen handelte, geht auch daraus hervor, dass das vorderste Gitter G_1 einsam (nach Entfernung der übrigen Gitter) die Wellen stärker reflektierte (die gestrichelte Kurve II in Fig. 5) als das ganze Gittersystem, wenn der Netzebenenstand in diesem einen Wert zwischen etwa 5 und 10 cm hatte.

7. Wenn die halbe Wellenlänge des Erregers und die des Empfängers = 15,0 cm waren (Kurve III in Fig. 5), entsprach dem Reflexionsmaximum ein Netzebenenabstand $d = 14{,}7$ cm. Auf senkrechte Inzidenz reduziert, beträgt dies 14,7 cos 12° = 14,4 cm, welcher Wert um 0,6 cm *kleiner* als $^1/_2\, \lambda_O$ (oder $^1/_2\, \lambda_R$) ist. Für $^1/_2\, \lambda_O = {}^1/_2\, \lambda_R = 15{,}9$ cm (Kurve IV in Fig. 5) ergab sich für den dem Reflexionsmaximum entsprechenden auf senkrechte Inzidenz reduzierten Netzebenenabstand der Wert 15,0 cos 12° = 14,7 cm, der um 1,2 cm kleiner als die halbe Wellenlänge ist. Für Wellenlängen, welche grösser als die Eigenwellenlänge der Gitterelemente waren, war also der dem Reflexionsmaximum entsprechende auf normale Inzidenz reduzierte Netzebenenabstand des Raumgitters etwas kleiner als die halbe Wellenlänge der einfallenden Wellen.

Für $^1/_2\, \lambda_R = {}^1/_2\, \lambda_R = 10{,}8$ cm (Kurve V in Fig. 5) entsprach dem Reflexionsmaximum ein auf normale Inzidenz reduzierter Netzebenenabstand = 13,7 cos 12° = 13,4 cm, welcher Wert mit der halben Eigenwellenlänge der Gitterelemente (z:a 13,3 cm) fast genau übereinstimmt. *Für eine Wellenlänge, die kleiner als die Eigenwellenlänge der Gitterelemente war, richtete sich demnach der dem Reflexionsmaximum entsprechende Netzbenenabstand vollständig nach*

der Eigenperiode der Gitterelemente, und bei grösseren Wellenlängen war auch, wie wir eben gesehen haben, *ein deutlicher Einfluss dieser Eigenperiode merkbar.*

8. Die Eigenschwingungen eines stabförmigen Leiters sind bekanntlich stärker gedämpft wie die eines ringförmigen von derselben periode und zwar nimmt die Dämpfung bei Verkürzung (bezw. Verkleinerung der Eigenperiode) des stabförmigen Leiters schnell zu. Es scheint demnach wahrscheinlich, dass die Ursache zu den beobachteten Verschiebungen der den Reflexionsmaxima entsprechenden Werte von d darin zu suchen ist, dass die Eigenschwingungen des geradlinigen Messresonators stärker gedämpft waren als die der ringförmigen Gitterelemente (die Dämpfung des mit Funkenstrecke versehenen Primärleiters O war natürlich noch viel grösser). Bei der Reflexion an dem Resonatorensystem machte sich also die Erscheinung der „multiplen Resonanz" besonders bei den kleineren Wellenlängen geltend. Unter den unendlich vielen Schwingungskomponenten, aus denen die primären Schwingungen zusammengesetzt gedacht werden können, wählte das Gitter diejenigen aus, deren Periode mit der seinigen übereinstimmte, und reflektierte — wenn die Hauptschwingungsperiode des Erregers kleiner als die Periode des Gitters war — hauptsächlich diese.

Wie ich früher nachgeweisen habe, besitzt ein aus ringförmigen Elementen bestehendes ebenes Gitter ein scharfes selektives Reflexionsvermögen. Die Gitterelemente reagieren dabei hauptsächlich auf die mit ihren Eigenschwingungen isokronen Schwingungskomponenten der primären Wellen und emittieren Sekundärwellen von ihrer eigenen Periode, die sich zu einer Eigenstrahlung des Gitters zusammensetzen.

Es geht dies besonders deutlich aus einigen Versuchen hervor, durch welche die an einem solchen Gitter reflektierte Strahlung durch Resonanzversuche in einem solchen Falle analysiert wurde, wo die einfallenden Wellen eine grössere Periode als die Gitterele-

mente hatten[1]. Es zeigte sich, dass die reflektierte Strahlung sich dann aus zwei Teilen zusammensetze, nämlich aus einer Eigenstrahlung (Floureszenzstrahlung), die mit den Eigenschwingungen der Gitterelemente isokron war, und einer zerstreuten oder erzwungenen Strahlung, deren Periode mit der der primären Wellen übereinstimmte. Während bei dem aus ringförmigen Elementen bestehenden Gitter die Eigenstrahlung die Hauptrolle spielte, war bei einem aus geradlinigen Resonatoren zusammengesetzten Gitter und in noch höheren Grade bei einem Kugelgitter die zerstreute (erzwungene) Strahlung dominierend. Es bildete dieses Ergebnis ein elektromagnetisches Analogon zu der von Barkla und Sadler[2] nachgewiesenen Zusammensetzung der sekundären Röntgenstrahlung aus zwei entsprechenden Komponenten.

Wenn bei den oben beschriebenen Versuchen über das Reflexionsvermögen des aus ringförmigen Elementen bestehenden Raumgitters der mit cos 12° multiplizierte Netzebenenabstand angenähert gleich der halben Eigenwellenlänge der Gitterelemente ist, verstärken die von den verschiedenen Netzebenen ausgehenden auf den Messresonator wirkenden Eigenwellen einander durch Interferenz und erzeugen dann, wie durch die Beobachtung bestätigt wird, ein Maximum der Eigenstrahlungsintensität. Ist die Periode der primären Wellen kleiner als die Eigenperiode der Gitterelemente, so kommt die zerstreute Strahlung neben der Eigenstrahlung kaum in Betracht. Bei grösseren Perioden der Primärstrahlung ist aber die Intensität der zuletzt erwähnten Strahlung von derselben Grössenordnung wie die Eigenstrahlung. Die reflektierte Intensität müsste dann eigentlich bei zwei verschiedenen Netzebenenabständen ein Maximum erreichen. Wenn aber — wie bei den obigen Versuchen der Fall war — der Unterschied zwischen der Periode der Primärwellen und der der

[1] K. F. Lindman, Über elektrische und optische Resonanz. Öfversigt af Finska Vet. Soc. Förh. L. VII 1914—1915, A. 2, p. 48—49. Ann. d. Phys. *45*, p. 620—621 bezw. p. 612—613 (1914).

[2] C. G. Barkla und A. Sadler, Phil. Mag. *16*, p. 550 (1908) — A. Sadler, Phil. Mag. *18*, p. 107 (1909).

Gitterelemente relativ klein ist, vereinigen sich diese beiden Maxima zu einem einzigen, wobei der entsprechende (auf normale Inzidenz reduzierte) Netzebenenabstand einen Wert zwischen der halben Wellenlänge der Eigenstrahlung und der der zerstreuten Strahlung annimmt.

Dass bei den Versuchen mit den 26 cm langen Wellen ($^1/_2\, \lambda_O = {}^1/_2\, \lambda_R = 13{,}0$ cm) sowohl das Maximum wie auch das Minimum der reflektierten Intensität (Kurve I in Fig. 5) um einige mm nach der Seite der grösseren Netzebenenabstände hin verschoben war, kann jetzt dadurch erklärt werden, dass die Eigenwellenlänge der Gitterelemente (λ = etwa 26,6 cm) ein wenig grösser als die erwähnte Wellenlänge der einfallenden Schwingungen war. Dass das Minimum sogar um etwa 2 mm mehr nach rechts verschoben war, als nach dieser Erklärung zu erwarten ist, ist wahrscheinlich auf Versuchsfehler bezw. eine Ungenauigkeit in der Bestimmung der Lage dieses Minimums zurückzuführen.

9. Da für Werte von λ_O und λ_R, die kleiner als die Eigenwellenlänge der Gitterelemente waren, die am Gitter reflektierte Strahlung nach der oben dargestellten Auffassung hauptsächlich aus der Eigenstrahlung des Gitters bestehen musste und diese Eigenstrahlung weniger gedämpft war als die Eigenschwingungen des geradlinigen Messresonators, bot das Gitter ein Mittel dar, stehende elektrische Wellen im Luftraume nachzuweisen, deren Länge von der Eigenperiode des Messresonators unabhängig war. Die diesbezüglichen Versuche, die gleichzeitig als Prüfung der erwähnten Auffassung dienten, wurden auf folgende Weise ausgeführt.

Primäre Wellen, deren halbe Länge ($^1/_2\, \lambda_O$) gleich 10,8 cm war, fielen auf eines der vorhin benutzten ebenen Gitter (halbe Eigenwellenlänge der ringförmigen Gitterelemente = 13,3 cm) unter einem Einfallswinkel von 40°. Die an diesem Gitter unter einem gleich grossen Winkel reflektierten Wellen fielen senkrecht auf einen 80 cm hohen und 50 cm breiten ebenen Kupferspiegel. Durch Intensitätsmessungen mit dem jetzt ohne Trichter und parabolischen Strahlensammler benutzten auf den Erreger abgestimmten geradlinigen Mess-

resonator ($^1/_2\,\lambda_R = 10{,}8$ cm) in verschiedenen Entfernungen von dem Kupferspiegel erhielt ich die Kurve I in Figur 6.

Ein Minimum der elektrischen Kraft lag demnach jetzt in der Entfernung 13,3 cm vom Spiegel, welcher Abstand mit der halben Eigenwellenlänge der Gitterelemente genau übereinstimmte. Irgend eines dem Werte $^1/_2\,\lambda_R = {}^1/_2\,\lambda_0 = 10{,}8$ cm entsprechendes Minimum ist nicht vorhanden. Die Länge der stehenden Wellen richtete sich somit nur nach der Periode der Gitterelemente, d. h. *die vom Gitter*

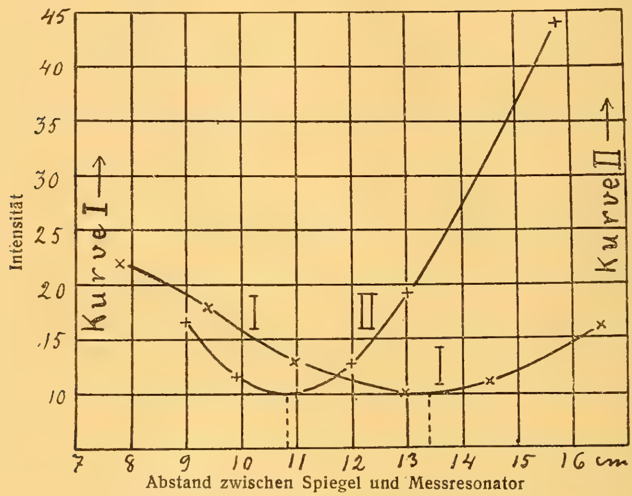

Fig. 6

emittierten sekundären elektromagnetischen Wellen waren durch diesen Versuch objektiv nachgewiesen.

Nachdem das Gitter durch einen ebenen Eisenspiegel ersetzt worden war, erhielt ich durch einen entsprechenden Versuch die Kurve II in Fig. 6. Die Abszisse des Minimipunktes dieser Kurve ist natürlich gleich $^1/_2\,\lambda_R$. Dass das Minimum der Kurve 1 weniger scharf ausgebildet ist als das der Kurve II[1], beruht offenbar dar-

[1] Wenn man die Verschiedenheit der Höhenskalen der beiden Kurven in Betracht zieht, so findet man, dass der Unterschied in der Schärfe dieser Minima jedoch nicht so gross ist, wie man nach dem ersten Eindruck von der Figur schliessen könnte.

auf, dass die Eigenperiode des Messresonators bei der Aufnahme jener Kurve mit der Periode der Eigenstrahlung des Gitters nicht übereinstimmte. Durch Abstimmen des Erregers zur Resonanz mit den Gitterelementen ($^1/_2\,\lambda_O = 13{,}3$ cm) hätte man eine bedeutend stärkere und wahrscheinlich auch noch weniger gedämpfte Sekundärstrahlung erzielen können. Da ich aber die oben für den Fall

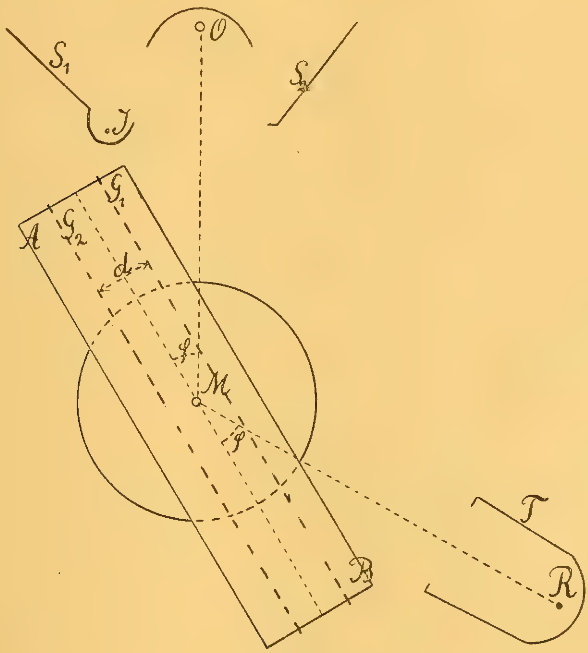

Fig. 7

$^1/_2\,\lambda_O = {}^1/_2\,\lambda_R = 10{,}8$ cm gegebene Erklärung der Wirkung des Raumgitters gleichzeitig prüfen wollte, sah ich hier von einer solchen Resonanzabstimmung ab.

Durch Benutzung eines Messresonators, dessen Eigenschwingungen stärker gedämpft waren als die des primären Erregers, habe ich früher[1] stehende elektromagnetische Primärwellen im Luftraume objektiv nachgewiesen.

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[1] K. F. Lindman, Öfvers. af Finska Vet. Soc:s Förh. LI, 1908—1909, A. 15 — Ann. d. Phys. *38* p. 523 (1912).

10. Ich machte schlieslich noch eine Reihe von Versuchen über das Reflexionsvermögen des Raumgitters bei verschiedenen Einfalls- bezw. Reflexionsvinkeln. Um den Einfallswinkel bequem variieren zu können, war bei diesen Versuchen das Resonatorensystem auf einem 2 m langen und 0,5 m breiten um ihre Mitte drehbaren Holzscheibe A B (Fig. 7) montiert (wie in der Figur angedeutet ist, lag die Scheibe A B auf einer kleineren Scheibe; ein Zapfen M diente als Drehungsachse). Vier der vorher benutzen ebenen Gittern waren dabei zu zwei miteinander parallelen um 28 cm voneinander entfernten ebenen Gittern G_1 und G_2 zusammengestellt. Um mehrere Reflexionsmaxima zu erhalten, musste der Abstand zwischen G_1 und G_2 grösser als die Wellenlänge (26,6 cm) sein, und da andererseits die verhältnismässig geringe Weite (33 cm) der Öffnung des Empfängertrichters T nur die Benutzung eines ziemlich eng begrenzten Strahlenbündels zuliess, hatte es keinen Zweck, eine grösse Anzahl von Netzebenen zu verwenden. Die ganze Versuchsanordnung geht übrigens aus Fig. 7 hervor (die Buchstaben *O, R, I,* S_1 und S_2 haben hier dieselbe Bedeutung wie in Fig. 4). Die Drehungsachse *M* der Scheibe *AB* war mittels dünner Bindfäden mit dem Oszillator *O* und dem Messresonator *R* verbunden. Der Winkel φ, den die einfallenden und die reflektierten Strahlen mit den Gitterebenen bildeten, wurde mit Hilfe einer Gradscheibe bestimmt. Der Abstand *OM* war = 1,8 m und der Abstand *RM* = 2,2 m. Beim Entfernen der Gitter G_1 und G_2 zeigte es sich, dass auch bei dem kleinsten angewandten Werte von φ (19°) der Erreger *O* keine merkbare direkte Wirkung auf den Messresonators *R* ausübte. Die halbe Eigenwellenlänge des Erregers und die des Messresonators waren bei diesen Versuchen = 13 cm.

Durch Messung der reflektierten Strahlungsintensität beim Varieren des Winkels φ erheilt ich die in Fig. 8 wiedergegebene Kurve. Obwohl die einzelnen fixen Punkte, zwischen denen die Kurve gezogen worden ist, nicht ganz regelmässig liegen — was vielleicht auf Störungen durch fremde Reflexionen (der um die Schirmöffnung gebeugten und am Gitter reflektierten Strahlen) zurückgeführt wer-

den kann — zeigt diese Kurve zwei gut ausgebildete Reflexionsmaxima für $\varphi =$ etwa 27° bezw. 68° und ein Minimum für $\varphi = 47°$. Wenn man die zu erwartende Lage der Reflexionsmaxima nach der Formel $2\,d\,sin\,\varphi = n\,\lambda$ (siehe Einleitung p. 7) berechnet und dabei λ gleich $26{,}6$ cm (die Eigenwellenlänge des Gitters) setzt, so erhält man $\varphi = 28{,}4°$ für $n = 1$ und $\varphi = 71{,}8°$ für $n = 2$, welche Werte in der Tat mit den beobachteten Werten 27° und 68° sehr nahe über-

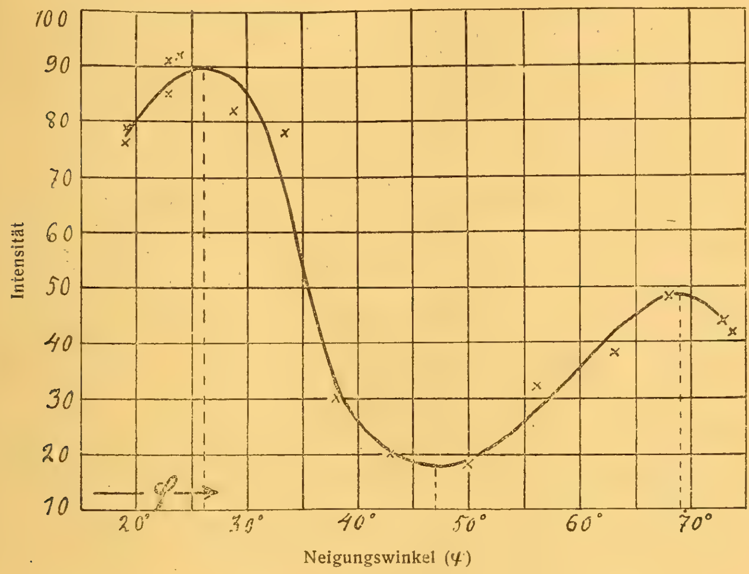

Fig. 8

einstimmen. Aus der Formel $2\,d$ sin $\varphi' = (n + 1)\,\frac{\lambda}{2}$ ergibt sich für die Lage des Minimums, wenn man $n = 1$ setzt, $\varphi' = 45{,}3°$, welcher Wert auch nur sehr wenig von dem beobachteten (47°) abweicht. Ohne sie auf Versuchsfehler bezw. eine mangelhafte Versuchsanordnung zurückzufüren zu brauchen, können die Unterschiede zwischen den beobachteten und den berechneten singulären Werten von φ (und φ') durch die durch besondere Versuche (siehe unten) festgestellte, mit wachsenden Einfallswinkeln $(90° - \varphi)$ folgende rasche Zunahme des Reflexionsvermögens der beiden Gitter G_1 und G_2 erklärt werden. Diese Zunahme des Reflexionsvermögens lässt

in der Tat eine Verschiebung der Maxima nach der Seite der grösseren Einfallswinkeln (kleineren Werten von φ) hin und eine nach der entgegengesetzten Richtung erfolgende Verschiebung des Minimums erwarten. Wenn von den betreffenden geringfügigen Verschiebungen abgesehen wird, *entsprechen also die obigen Beobachtungen über die Lage der Reflexionsmaxima vollständig dem zweiten* Bragg'*schen Gesetze* für die Reflexion der Röntgenstrahlen an Kristallen (Formel $2\,d \sin \varphi = n\lambda$). Dass bei den Bragg'schen Versuchen die Reflexionsmaxima im Gegensatz zu den hier beobachteten ausserordentlich scharf ausgebildet sind und bei anderen Einfallswinkeln kaum eine merkliche Reflexion stattfindet, ist dadurch bedingt, dass bei jenen Versuchen die einfallenden Strahlen eine scharf ausgebildete Periode hatten („homogene" oder „monokromatische" Strahlen) und nicht nur zwei, sondern eine ungeheuer grosse Anzahl äquidistanter Netzebenen als Reflektoren für die Wellen dienten. Wegen der scharfen Form dieser Reflexionsmaxima konnte eine durch ihren Höhenunterschied bedingte merkbare Verschiebung ihrer Lage auch nicht stattfinden.

11. Nach der Kurve in Fig. 8 ist die Intensität des Reflexionsmaximums erster Ordnung ($n = 1$) nicht ganz zwei mal so gross wie die des Maximums zweiter Ordnung ($n = 2$). Wenn der Winkel φ wächst, nimmt die Anzahl der von dem primären Strahlenbündel getroffenen Elemente jedes Gitters (G_1 und G_2) in umgekehrtem Verhältnis zu $\sin \varphi$ ab, und wenn das Reflexionsvermögen jedes Gitters in diesem Verhältnis abnehmen würde, so sollte aus diesem Grunde das zweite Maximum der Kurve in Fig. 8 halb so hoch sein wie das erste. Dass es in Wirklichkeit noch ein wenig höher ist, könnte dann dadurch erklärt werden, dass bei den Beobachtungen nicht das ganze reflektierte Strahlenbündel, sondern nur der mittlere Teil desselben in den Empfängertrichter gelangte, wobei dieser Teil mit wachsenden Werten von φ zunahm. Um die erwähnte Annahme über die Abhängigkeit des Reflexionsvermögen der Gitter von dem Werte des Winkels φ zu prüfen, machte ich

einige Versuche mit dem Gitter G_1 (Fig. 7) nachdem das zweite Gitter (G_2) entfernt und G_1 nach der Mitte der Scheibe AB verschoben worden waren. Es ergab sich, dass die am Gitter G_1 reflektierte Intensität für $\varphi = 69°$ 40 Proz. von derjenigen war, die dem Werte $\varphi = 22°$ entsprach. Die von dem einfallenden Strahlenbündel getroffenen Teile der Oberfläche des Gitters verhalten sich in diesen beiden Fällen wie sin 22° zu sin 69° oder 40,3 zu 100, welches mit der Beobachtung vollständig übereinstimmt. *Die am Gitter reflektierte Strahlung war* also *dem sinus des Winkelns φ oder dem cosinus des Einfallswinkels umgekehrt proportional*, was damit gleichbedeutend ist, dass *beim Variieren des Einfallswinkels die reflektierte Intensität der von den einfallenden Strahlen getroffenen Anzahl der Gitterelemente direkt proportional war.* Es fragt sich, wie dies möglich ist, da ja bei wachsenden Einfallswinkeln die auf die einzelnen Gitterelemente fallenden Strahlenbündel immer enger werden (die Projektion des ringförmigen Resonatorkreises auf die Wellenebene der einfallenden Strahlen ist dem cosinus des Einfallswinkelns proportional). Bei normaler Inzidenz wirkt nur der elektrische Vektor auf die ringförmigen Elemente. Bei schiefer Inzidenz wirkt aber nicht nur der elektrische, sondern auch der magnetische Vektor und zwar nimmt bei wachsendem Einfallswinkel die Wirkung des letzteren zu, so dass die totale Wirkung lieber zu-als abnimmt.[1]

Nach den Bragg'schen Untersuchungen über die Reflexion der Röntgenstrahlen an Kristallen würde die Intensität der Reflexion n:ter Ordnung für gleiche äquidistante Netzebenen nahe proportional $1/n^2$ sein, während Darwin,[2] der diese Frage theoretisch behandelt hat, zu dem Schlusse kommt, dass die reflektierte Intensität proportional $1/n$ sein sollte.

[1] Durch Versuche mit einem ringförmigen Messresonator fand ich, dass wenn dieser Resonator sich in der Schwingungsebene der primären Wellen befand, so dass sowohl der elektrische wie der magnetische Vektor maximal auf ihn wirkte, die mit ihm gemessene Intensität etwas, aber nicht viel grösser war, als wenn der Resonatorkreis zur Wellenfläche parallel war, in welchem Falle nur der elektrische Vektor auf ihn wirkte.

[2] C. G. Darwin, Phil. Mag. April 1914, p. 689.

Obwohl die letztere Folgerung den Ergebnissen meiner Versuche recht gut entspricht, darf dies nicht als eine Bestätigung der Darwin'schen Theorie betrachtet werden, da diese Theorie die Atome der Kristalle keineswegs als ringförmige Resonatoren ansieht. Ewald,[1] welcher auch das Reflexionsgesetz der Röntgenstrahlen teoretisch untersucht hat, nimmt allerdings an, dass die Atome sich wie schwingungsfähige Dipole verhalten. Aus gewissen Beobachtungen zieht er aber den Schluss, dass die Eigenperiode dieser Dipole — wenigstens bei gewissen Kristallen — gross gegen die der benutzten Wellen sei.[2] Es ist dies ein wesentlicher Unterschied zwischen den Versuchen über die Röntgenstrahlinterferenz in Kristallen und den oben beschriebenen in mehreren Beziehungen sonst analogen Versuchen über die durch ein Raumgitter erzeugte Interferenz der Hertz'schen Wellen. Bei einer vollständigen theoretischen Erörterung dieser Versuche müsste auch — wie Ewald es für die Röntgenstrahlinterferenz getan hat — die gegenseitige Beeinflussung der zu den verschiedenen Netzebenen gehörigen Gitterelemente in Betracht gezogen werden.

V. ZUSAMMENFASSUNG.

Durch die oben beschriebenen Versuche ist eine durch ein dreidimensionales System von ringförmigen Resonatoren erzeugte Interferenz der elektromagnetischen Wellen nachgewiesen worden, die in mehreren Beziehungen ein elektromagnetisches Analogon zu den Bragg'schen Versuchen über die Röntgenstrahlinterferenz in Kristallen bildet.

Die Resonatoren waren in äquidistanten hintereinander stehenden Netzebenen in gleicher Weise angeordnet und hatten eine halbe Eigenwellenlänge von etwa $13{,}_3$ cm. Durch Versuche mit 26 cm langen Wellen (um eine genügend starke Reflexion zu erhalten,

[1] P. E. Ewald Ann. d. Phys. 54 p. 519 (1917).

[2] P. E. Ewald Physikalische Berichte, 2, H. 1. p. 59 (1921).

mussten die primären Wellen mit den Eigenschwingungen der Gitterelemente angenähert isokron sein) ergaben sich zunächst die folgenden Gesetze für die Reflexion der Wellen an dem Raumgitter.

1) Einfallswinkel = Reflexionswinkel.

2) Die Intensität der reflektierten Strahlung erreicht für gewisse Einfallswinkel Maximiwerte und zwar lassen sich diese Winkel *(i)* durch die Formel

$$2\ d \cos i = n\ \lambda.$$

darstellen, worin n kleine positive ganze Zahlen (die Ordnungsnummern der Reflexionsmaxima), d den Netzebenenabstand und λ die Wellenlänge bezeichnen (geringfügige Differenzen zwischen den beobachteten und den nach dieser Formel berechneten Werten von i konnten auf einen Einfluss der mit wachsenden Einfallswinkeln folgenden Zunahme des Reflexionsvermögens der einzelnen Gitter zurückgeführt werden).

Diese Gesetze entsprechen vollständig den beiden ersten fundamentalen Gesetzen, welche die Herren Bragg für die Reflexion der Röntgenstrahlen an Kristallen aufgestellt haben. Wegen der Dämpfung der elektrischen Schwingungen waren jedoch die mit den elektrischen Wellen erhaltenen Reflexionsmaxima bei weitem nicht so scharf ausgebildet wie die mit monokromatischen Röntgenstrahlen erhaltenen. Zwischen den beiden beobachteten Reflexionsmaxima befand sich ein Minimum, dessen Lage durch die Formel $2\ d \cos i_1 = (n + 1) \frac{\lambda}{2}$ bestimmt wird, wenn i_1 den diesem Minimum entsprechenden Einfallswinkel bezeichnet und n gleich 1 gesetzt wird.

Die Intensität eines Reflexionsmaximums war der Ordnungsnummer des Reflexes annähernd umgekehrt proportional, welches dadurch bedingt sein dürfte, dass — wie durch besondere Versuche festgestellt wurde — das Reflexionsvermögen der einzelnen ebenen Gitter dem cosinus des Einfallswinkels umgekehrt proportional oder, was damit gleichbedeutend ist, der Anzahl der von dem einfallenden Strahlenbündel getroffenen Gitterelemente direkt proportional war. Nach den Bragg'schen Versuchen ist dagegen bekanntlich die Inten-

sität des Röntgenstrahlreflexes dem Quadrate der Ordnungsnummer proportional, während sie nach Darwin's theoretischen Betrachtungen der Ordnungsnummer selbst proportional sein sollte. Obwohl die letztere Folgerung mit dem soeben erwähnten Ergebnis dieser Untersuchung im Einklang steht, darf dies nicht als eine Bestätigung der Darwin'schen Theorie betrachtet werden, da diese Theorie die Atome der Kristalle keineswegs als ringförmige Resonatoren ansieht. Insofern man die Kristallatome als elektrische Dipole angesehen hat (Ewald), hat sich — wenigstens bei gewissen Kristallen — ihre Eigenperiode als gross gegen die Periode der Röntgenstrahlen (bezw. β-Strahlen) ergeben. Es ist dies ein wesentlicher Unterschied zwischen den Versuchen über die Röntgenstrahlinterferenz in Kristallen und den in dieser Arbeit beschriebenen Versuchen.

Durch Messung der an dem Resonatorensystem unter einem konstanten und möglichst kleinen Einfalls- bezw. Reflexionswinkel (12°) reflektierten Strahlungsintensität ergab sich beim Variieren des Netzebenenabstandes *(d)*, dass, wenn Oszillator, Messresonator und Gitterelemente angenähert isokron waren, der dem Reflexionsmaximum entsprechende auf normale Inzidenz reduzierte Netzebenenabstand ($d \cos 12°$) angenähert gleich der halben Länge der einfallenden Wellen war. Für eine Periode des Oszillators und des auf ihn abgestimmten Messresonators, die kleiner als die Eigenperiode der Gitterelemente war, richtete sich dagegen der dem Reflexionsmaximum entsprechende Netzebenenabstand vollständig nach der Eigenperiode der Gitterelemente, und bei grösseren Perioden des Oszillators und des Messresonators war auch ein deutlicher Einfluss der Eigenperiode der Gitterelemente merkbar. Es konnte dies dadurch erklärt werden, dass die am Gitter reflektierte Strahlung sich im allgemeinen aus zwei Teilen zusammensetzte, nämlich aus einer Eigenstrahlung (Fluoreszenzstrahlung), die mit den Eigenschwingungen der Gitterelemente isokron war, und einer zerstreuten oder erzwungenen Strahlung, deren Periode mit der der primären Wellen übereinstimmte (es bildete dies ein Analogon zu der von Barkla und Sadler

nachgewiesenen Zusammensetzung der sekundären Röntgenstrahlung aus zwei entsprechenden Komponenten). Wenn die Periode der primären Wellen kleiner als die der Gitterelemente war, dominierte die Eigenstrahlung des Gitters, während bei grösseren Perioden der Primärstrahlung die beiden Komponenten der reflektierten Strahlung sich geltend machten und eine Verschiebung des Reflexionsmaximums nach der Seite der grösseren Werten von d hin herbeiführte.

Durch Messung der von dem Resonatorensystem durchgelassenen mit den Eigenschwingungen seiner Elemente annähernd isokronen Strahlung beim Variieren des Netzebenenabstandes (d) ergab sich eine Interferenzkurve, deren Maximum und Minimum mit Bezug auf ihre Lage mit dem Minimum bezw. Maximum der entsprechenden Reflexionskurve übereinstimmten. Einige derartige Durchlässigkeitsversuche mit einem dreidimensionalen Resonatorensystem hatte Verfasser schon im Winter 1910 ausgeführt. Sie bildeten auch den Ausgangspunkt für die vorliegende Arbeit.

Da für Perioden des Erregers und des Messresonators, die kleiner als die Eigenperiode der ringförmigen Gitterelemente waren, die am Gitter reflektierte Strahlung hauptsächlich aus der Eigenstrahlung des Gitters bestand und diese Eigenstrahlung weniger gedämpft war als die Eigenschwingungen des geradlinigen Messresonators, bot die Sekundärstrahlung des Gitters ein Mittel dar, stehende elektrische Wellen im Luftraume zu erzeugen, deren Länge von der Eigenperiode des Messresonators und der des primären Erregers unabhängig war und sich nur nach der Eigenperiode der als sekundäre Emissionszentra wirkenden Gitterelemente richtete. Solche im Luftraume objektiv vorkommende stehende elektrische Sekundärwellen konnten in der Tat durch einen Versuch nachgewiesen werden, bei dem die Eigenstrahlung des Gitters an einem ebenen Metallspiegel in normaler Richtung reflektiert wurde (objektiv im Luftraume vorkommende stehende elektrische Primärwellen sind vom Verf. früher nachgewiesen worden.)

Åbo, Physikalisches Institut der Akademie, im Februar 1921.

ACTA ACADEMIAE ABOENSIS
MATHEMATICA ET PHYSICA I:4

ON THE LITHOLOGY AND GEOLOGICAL STRUCTURE OF THE SIERRA DE UMANGO AREA, PROVINCE OF LA RIOJA, ARGENTINE REPUBLIC.

A CONTRIBUTION TO THE KNOWLEDGE OF THE SUBANDEAN BORDER OF THE STRUCTURAL ELEMENT OF THE „SIERRAS PAMPEANAS".

BY

H. HAUSEN, PH. D.

ÅBO AKADEMI
ÅBO 1921

ÅBO 1921
ÅBO TRYCKERI OCH TIDNINGS AKTIEBOLAG

PREFACE.

Engaged as geologist of the Direction of Mines, Section of Geology, Buenos Aires, during the years 1914—17, I had to explore the geological structure of a mountain complex, situated in the western part of the province of La Rioja, near the border of the Cordillera and named *La Sierra de Umango*. I started from Buenos Aires in beginning of may 1915 and returned in august the same year. Simultaneously with me a topographer from the Section of Topography, Direction of Mines, was committed with the mapping of the region. His map could, however, be used only at a time after my return to Buenos Aires, and later on I had no occasion to start a new expedition to this region with its very complicated geology for bringing the observations into closer accordance with the topographical map.

The geological sketch map, covering the reduced copy of the above named topographical sheet, accompanying this paper, expresses of course only the main geological features. In order to illustrate the intricate relations of the rock members of the area (mingled rocks, veins, banded schists, etc.) a map of much greater scale would be necessary. The petrographical descriptions below may, however, give a picture of the lithological relations, and that will be the chief purpose of the present paper.

The task of exploration of the Sierra de Umango area was undertaken on proposal of Dr Hans (Juan) Keidel, Director of the Section of Geology, Buenos Aires, in order to obtain a closer knowledge on the first hand of the relations between the structural element of the „*Sierras pampeanas*" to the east and the permian and andean (tertiary) structures to the west. That this matter of study really was to be found in the Sierra de Umango area, seemed probable already from an examination of the geological map of Ludwig Brackebusch (Gotha, 1891).

The geological mapping of the Sierra de Umango area should also be a continuation of the field works carried out in the near lying province of Catamarca by the geologists of the Direction of Mines, Dr Walther

Penck and Dr Juan Rassmuss, where ancient metamorphic rocks analogous with them of the Sierra de Umango are the predominant.

The present paper is a somewhat modified edition or rather a working up in english of my original spanish report, addressed to the Direction of Mines, Buenos Aires. The later will be printed in the Bulletin of the Direction (Serie B, Geología).

I am much obliged to the Direction of Mines and especially to the Director General, Engineer E. Hermitte, for the obtained permission to publish this memoir in an independent way.

Academy of Åbo, Finland. September 1921.

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[1] All the landscape views and profiles sketched by the anthor.

PHYSIOGRAPHY OF THE AREA.

Sierra de Umango is the general name of a mountain group, situated in the deep corner between the eastern border of the Cordillera in the west, the southern edge of the Puna de Atacama in the north and the lofty, meridionally streching ridge of the Sierra (and Nevado) de Famatina in the east. It lies in the western part of the province of La Rioja, in the extremely dry, so called *subandean zone* of the central western Argentina. The closer position of the area is defined by the coordinates 28° 50′—29° 50′ S Lat. and 68° 00′—69° 00′ W Long. from Greenwich. The geological study in this region comprises, however, more than the topographical unity of the Sierra de Umango and extends sometimes to the foothills of the surrounding mountains. The approximate limits of the surveyed area are thence: in the west: the eastern border of the Cordilleran block, or nearer said the „Precordillera", marked by the steep western wall of the tectonical valley Guandacol — Tambillos — Guandacolinos, and further to the north by the western border of the Bolson de Jaguel; in the north by the southern edge of the Puna de Atacama; in the east by the western slope of the Sierra (Nevado) de Famatina; in the south the southern limit of the alluvial plain of Pagancillo and the water gap of the little river Vinchina, above its confluence with the Rio Bermejo. (See the accompanying map!)

Regarding the orography, two elements may be distinguished: 1) the alpine mountains of the Sierra de Umango in proper sense, the Cerro Cacho and the Cerro Villa Union, all comprising the old crystalline rock ground, and 2) the surrounding foothills with the

lowland ridges, built up by soft, younger rocks, principally of clastic origin. Of the lofty „crystalline“ mountains, the Cerro Cacho lies nearest to the Cordilleran border and is for a distance of some miles closely united with the later (Pampa de Leoncito). Separated from the Cerro Cacho by a relatively hilly highland surface there follows to the east the very ridge of the Sierra de Umango, running NE--SW, with a somewhat lower and shorter parallel chain to the east, the Cerro La Pampa. To the SE off these ridges lies the more isolated complex of the Cerro Villa Union, on all sides surrounded by alluvial deposits.

All the named mountains are of quite considerable heights, as shown by the following data:

Cerro Cacho	4,660—4,405	m ab. the sea.
Sierra de Umango ridge ...	4,300—4,275	„ „ „ „
Cerro Villa Union..........	4,285	„ „ „ „

The absolute heights of the valleys vary between 910 and 2,200 m. The foothills and the lowland ridges of softer rocks and also isolated groups of the old basement rocks (Villa Castelli) attain only some hundred meters over the valley floors. Of greater importance among the foothills are the Cerros de San Antonio to the S from the Sierra de Umango ridge, the Cerro Bola SSE from the Cerro Villa Union, the Cerro Colorado, lying immediately to the east of the Cerro Villa Union and at last the broad ridge, well marked by a cuesta to the E, forming the dividing line between the Jaguel bolson and the Vinchina valley in the direction NE from the Sierra de Umango. (See the topographical map!)

The whole western part of the province of La Rioja belongs to the climatic province of broader sense called by G. Davis[1] „*La zona andina*“. This is, as known, characterized as a dry desert, where rainfall occasionally occurs only in summertime, when the Eastwind blows (from the pampa). In the higher mountains a western storm

[1] El clima de la República Argentina. Buenos Aires. 1909.

called „*la zonda*“ is thundering on nearly the whole year. This wind is cold and dry and originated probably by a great, permanent minimum, extending over the pampean plain further eastward.

The summits of the Umango Mountains are never snow clad. Only the giants outside the area, reaching up to more than 6,000 m, such as the volcan Cerro Bonete on the Puna-edge and the Nevado de Famatina, carry a white cap. The snowfall here is more abundant during the summer than the dry wintertime.

Fig. 1. Key Map.
◉ The Sierra de Umango Area.

A peculiar scenery of these deserts are the heavy skyfalls in the moist season, the so called „*crecientes*“. When such an outburst occurs on a mountain slope, all the dry „*quebradas*“ or gorges are filled by rushing streams, loaded with boulders and gravels, sand and mud, cutting through old piedmont deposits, filling preexistent channels and forming new ones in the broad alluvial fans, radiating

from the mouth of every „*quebrada*“ into the valley floor outside the mountains. The rugged topography of the area, often a veritable „Bad Land“, is doubtless the result of the intense, but sporadic work of the named „*crecientes*“.

The day-temperature is generally high all the year round. During the wintermonths the thermometer often reaches 20° C, resulting from the intense insolation. The nights are cold with 10° and more below the zero. On heights ab. 4,000 m the temperature is generally low even at daytime, because the icy „*zonda*“ never ceases to blow.

Running waters are, except the sporadical „*crecientes*“, extremely scarce in the Sierra de Umango area. Over the sandy bottom of the Guandacol valley the little Rio Bermejo is meandering southwards to the *bolsons* in the province of San Juan (see below, page 120) farther south. This river receives from the left hand an insignificant tributary, the Rio Vinchina, coming from the broad valley, which separates the Sierra de Umango from the Nevado de Famatina. Its upper course is draining the *bolson* of Jaguel through the water gap opposite the Vinchina settlement. Both rivers are speeded by underground waters, and a source can hardly be fixed.

All the mountain valleys and gorges are dry.

A continuous vegetation is never to be seen, except the „*pastorales*“ on great heights, where a hard grass grows, serving as food to the cattle. The „*barrancas*“ in the dry valley trains are sometimes bordered by algarrobo trees („gallery woods“), indicating the course of the underground waters. In the immediate vicinity of the water springs, generally scarce, and occuring either at the foot of a mountain or on the bottom of a „*quebrada*“, there grows a high grass, called by the natives „*carrizales*“. The open plains of alluvial gravel, sand and loess are dotted by xerophil thorn-bushes and various kinds of cactus. The most characteristic form of the northwest-argentine deserts, the giant cactus *(cereus giganteus)*, is completely lacking in the Sierra de Umango area; it does not extend westward from the Nevado de Famatina.

The settlements are not frequent, especially the villages. These exist on irrigation culture. The grape cultivating Villa Union and the Villa Vinchina are the most important, both consisting of claybuilt block houses, forming rectangular „*quadras*“, separated by muddy streets. Outside the dwellingplaces there extend the vineyards, pastures and a network of very primitive irrigation channels. Both villages receive their water supply from the Rio Vinchina.

In the mountains there are several small „*puestos*“ or „*pircas*“, stone dwellings, inhabited by „*gauchos*“, a poor halfblood, watching sheeps and cattle.

The region lies quite outside the lines of communication and far away from greater centres of population of the Republic. The nearest railway station is Chilecito, on the eastern side of the Nevado de Famatina, the end of the Serrezuela branch of the Córdoba—La Quiaca railway (Ferrocarril del Norte Argentino). The way from Chilecito to Villa Union is a riding path over a quite rough ground and running across the southern, lower part of the Nevado de Famatina. The freights from and to Villa Union are carried on mule- and donkey-back.

HISTORICAL REVIEW OF THE GEOLOGICAL EXPLORATION OF THE WESTERN PART OF THE PROVINCE LA RIOJA.

In the mining history of the Argentine Republic the province of La Rioja plays a very important part. Already since times of the spanish jesuits work has been done in these distant and desertous mountains for the search and exploitation of many rich minerals of gold, copper and silver. Especially in the famous Nevado de Famatina the mining work has been very productive. A rational exploitation of the ores there began, however, about fifty years ago, and since this time the mining industry here has been in a steady progress. The newly built railway from Serrezuela (Prov. de Córdoba) to Chilecito (situated on the eastern side of the Nevado de Famatina) and the electric wire rail from Chilecito up to the mines of La Mejicana, in an alture of about 5000 m. (ab. the sea) on the E slopes of the Nevado, give an evidence of the intensity of exploitation in the last times. At present (1917) the whole business is, in consequence of various circumstances, stopped.[1]

In comparison with the extensive prospecting work of all the mineral occurrences in these regions, the progress of the geological exploration has been quite insignificant, especially when regarding the old crystalline rocks, appearing as the main components of the mountain blocks of the Sierra de Velazco, the Sierra de Famatina and the Sierra de Umango.

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[1] Regarding the mining history of the Nevado de Famatina, see: A. Stelzner (1876—1885), and E. Hermitte: La minería argentina. Buenos Aires 1915.

The pioneer investigator in the named regions was the german Dr A. Stelzner (1876—85)[1] a late professor of geology at the University of Córdoba. During the summer 1871—1872 he traversed the province of Catamarca (in the N) and arrived also southward to the Nevado de Famatina with the purpose of making a slight investigation in all the mining fields here. During this trip Stelzner made an important discovery. In Potrero de los Angulos, on the

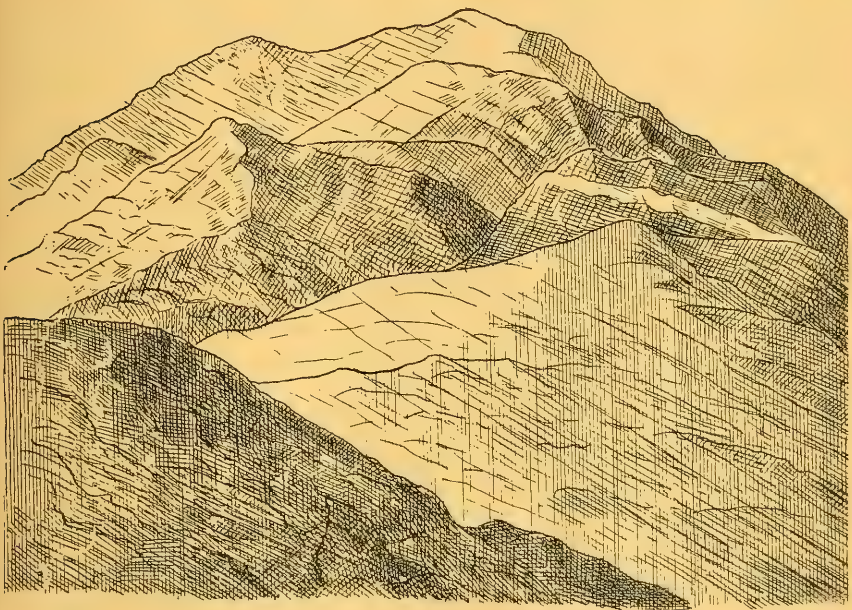

Fig. 2. The Morro alto de Cordobés (about 4300 m.), Sierra de Umango ridge, seen from the south. The eastward dipping lines indicate the zone of lustering mica schists (see pag. 17).

eastern side of the mountain he found fossiliferous schists of silurian age. The fossils were later described by E. Kayser (see later on). In his report Stelzner says, that the Nevado de Famatina differs from the so called „Sierras pampeanas“ by the absence of gneissic rocks and by the predominance of slaty and quarzitic schists, further by more clastic members, having in common only the large granitic bosses.

[1] Compare the bibliography.

A second expedition of Stelzner, realized during the following summer, was directed to regions more to the south, into the province of San Juan. During this journey Stelzner's object of study was principally the continental, clastic formations, reposing with great unconformity on the metamorphic schists. He discovered a rhaetic flora, since closer examined by Geinitz (1876).

The next geologist, who visited these regions, was Dr L. Brackebusch, formerly professor of geology at Córdoba too. During extensive and audacious journeys, this infatigable explorer twice crossed the region of the Sierra de Umango. In his „*Mapa geológico del interior de la República Argentina*“ [1] he has fixed, according to his and Stelzners observations, the main geological contours of these regions. Brackebusch divided the formations here as follows: 1) archaean, 2) rhaetic, 3) tertiary and quaternary. The whole material collected by Brackebusch was then handed over to various specialists in Germany, where also all the results were published. As these laboratory-investigations generally were carried out without any geological basis, their value is only a descriptive mineralogical one (resp. palaeontological). It is a pity, that Brackebusch never got any occasion to publish all his own extensive impressions except what „Mapa geológico del interior de la República Argentina“ contains.

During the later years Dr W. Bodenbender, at present professor of geology at Córdoba, has carried out a more systematic regional investigation in the western provinces, partly in the subandean region of La Rioja (1911). The Sierra de Umango area was, however, visited by him only to a small extent, principally along the borders of the Cerro Villa Union. But his exploration of the southern part of the province of La Rioja and also his monographical treatment of the Nevado de Famatina (1916), Sierra de Umango's neighbour to the E, has offered much of comparative material to the study of the Sierra de Umango-geology.

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[1] Scale 1: 1,000,000. Gotha 1891.

In still later time Dr Walther Penck, formerly geologist of the Direction of Mines, at present professor of geology at the University of Leipzig, Germany, has investigated the area of the Bolson de Fiambalá and surrounding mountains, lying in the province of Catamarca and in the NE continuation of the Sierra de Umango complex. The results of these works are: a geological map in the scale 1: 200,000, preliminary reports (1914/15) and a complete geological-morphological monography (1920) of „the southern border of the Puna de Atacama“, as he names the region.

The main results of W. Penck may not be mentioned here, because in the following pages it will be various occasions to return to his works. It may only be stated here, that the peculiar banded structure of the Sierra de Umango metamorphic series is continuing far into the Catamarca mountains and that the continental overlapping strata show a great similarity to the La Rioja beds.

Simultaneously with my own camp works in the Sierra de Umango area, my colleague Dr Juan Rassmuss was carrying on an investigation in the adjacent part of the „Precordillera“ to the W and SW from the Sierra de Umango. The result of Rassmuss is hithertoo, so far as I know, a handcolored geological map. His verbal communications have been to great use for my own purposes.

PART I.

LITHOLOGY OF THE CRYSTALLINE, GRANITE-INTRUDED BASEMENT.

A) THE "PREGRANITIC" SUPERCRUSTAL ROCKS OF THE SIERRA DE UMANGO AREA.

a) THE SEDIMENTARY SCHISTS.

Engaged in a careful study of the lithological composition of the Sierra de Umango crystalline basement, one must arrive at the conclusion, that there is a great bulk of sedimentary and effusive members, — a „pregranitic“ unity, while granites older than the postsilurian(?) Famatina granite, do not occur there. The sedimentary part of this bulk consists principally of three distinct lithological groups: *limestones, quartzitic schists* and *argillaceous schists*. The relative quantities of these components are very difficult to estimate, because the original succession is lost by various processes of disturbances, causing faults, folds, charriages (overthrusts), etc. with accompanying thickening and inversion of the strata. The limestone-amphibolite banks with their fantastic torsion phenomena offer an evident proof of the high grade of disturbances, suffered by the basement in question (see the fig. 3).

A conspicuous circumstance is the great thickness of the limestone banks especially in the western part of the region, where the limestone alone forms whole ridges and hills, the total thickness of the ayers attaining some hundred meters without any tectonical thickening. This abundance of limestone stands in a marked contrast to the experiences in the Famatina mountain, where such layers are thin and scarce [1]. Also in the other pampean sierras we find

[1] See: G. Bodenbender (1916).

limestone to quite an insignificant extent, except in some parts of the Sierra de Córdoba and in the Sierra de la Huerta [1].

Among the other sedimentary members in the Umango pregranitic series the micaschists occupy different, broad zones, the most important of them being a more central one. The quartzitic schists are always intercalated in these rocks, partly in regular alternation, partly in mightier zones.

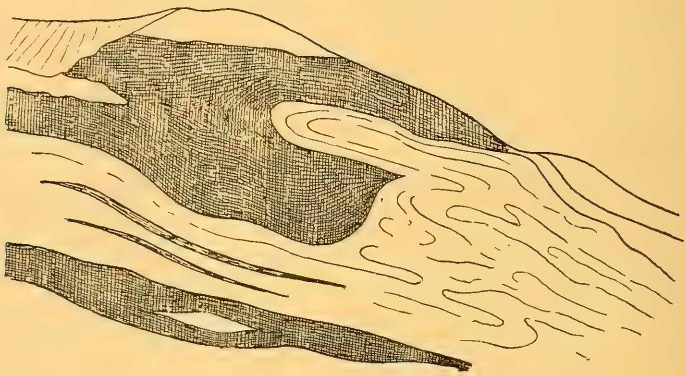

Fig. 3. Contorted and thickened layers of silicious limestone (white) in micaschist (grey). NW from Carrizal. Height of the rock-wall about 50 m.

Apart from these principal types to a smaller extent we find interstratified members of strongly pressed, dark schists. These may be considered partly of sedimentary, partly of pyroclastic origin.

All these layers form a concordant prism without any sign of break in the sedimentation. Conglomeratic layers are completely lacking.

Below follows a closer lithological characteristic of the named sedimentary types.

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[1] A. Stelzner: Mineralogische Beobachtungen im Gebiete der Argentinischen Republik. Tscherm. Min. und Petrograph. Mittheilungen. IV. 1873. Pag. 230, and foll.

The *limestone* is characterized by a high grade of purity. This circumstance has caused, that a skarn (silicatic) mineralization very seldom occurs, in spite of the abundant, crossing granitic veins. In some parts there may be found a hornstone, a characteristic mark of the precordilleran silurian limestone, and formed probably from remnants of silica-bearing organisms *(radiolaria).* The mightier layers of the limestone are generally divided into thinner banks by joint planes, seldom by intercalations of foreign matter. The banking of the rock marks very well the folding and torsion phenomena. In handspecimen the rock shows generally an evengrained structure (sugargrained) and the colour is mostly pure white. In some parts there are very excellent kinds of marble. An analysis of the limestone of usual habit from the Cerro Potrero Viejo, near to the Puesto del Agua, was obtained from the Chemical Laboratory of the Ministery of Agriculture, Section Mineral Waters, Buenos Aires:

SiO_2	4,65 %
CO_2	41,09 %
CaO	35,30 %
MgO	13,77 %
Al_2O_3 / Fe_2O_3	3,40 %
Total	98,21 %

From this analysis it is evident that the rock contains a considerable amount of MgO, but not to such a degree, as to be named dolomite.

Other crystalline limestones from the area of the pampean sierras, i. e. the quarry Rio del Sauce, Sierra de Córdoba, whose analysis-data were communicated by my colleague Dr R. Beder, show scarcely more than traces of MgO in eleven limestones analysed. Over all the Córdoba-limestones (Malagüeño, Santo Do-

mingo, Alta Gracia, Mal Paso, etc.) are very poor in MgO.[1] The Córdoba limestones are considered of lower silurian age.[2]

The limestones of the Precordillera, i. e. of silurian age too, but unmetamorphosed, from Salagasta, province of Mendoza, show very small amounts of MgO.

Microscopically the Umango limestone shows a structure of isometric grains, with quite angulated contours. The characteristic twinning-lamellae after — $^1/_2$ R are shown elsewhere. Accessoric minerals are met with only at a small extent and consist principally of quartz and sericite. A dominant direction in the structure is lacking and also every sign of kataclasis.

In parts where the limestone occurs only as thin interstratifications in quartzitic schists etc., it has a more grayish-bluish colour and shows almost a banded transition to the neighbouring rock.

A common feature is a banded intercalation of basic effusive layers (amphibolitic schists) in the limestone, a peculiarity treated off later on.

The *quartzitic schists* occur, as stated above, partly as broader, partly as thinner zones or interstratifications. In the first case more schistose types of grey and dark colours are met with on the eastern slope of the Sierra de Umango ridge. In the second case there are milkwhite, glassy layers or more concordant veins. The quartzitic schists have the schistosity planes marked by mica (biotite), often leading to quartzitic mica schists. The milkwhite quartz veins of layer-appearance occur principally in mica schists, where there are also thin layers of limestone. The intimate alternance between these layers may produce a marked banding structure on the rock surfaces (comp. later on).

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[1] A. Cogliati: Consideraciones sobre algunos calcareos y cementos de la República Argentina. Buenos Aires.

[2] H. Keidel (1914), page 674, and R. Beder: Las cales cristalino-granulosas de la Sierra de Córdoba y sus fenómenos de contacto. Dirección G:ral de Minas, Geol. e Hidrolog. Boletin num. 7. Serie B. Buenos Aires 1914.

On the transverse fracture surfaces of the very quartzitic schists may be observed too quite a distinct glassy habit. These rocks are, as shown later on, strongly recrystallized. The mica marks the very bedding planes of the rock (Pl. I, fig. 1), as becomes evident from the fact, that these schists partly carry interstratifications of sericitic schists. With regard to the relatively considerable amount of mica in the mass of the schists, it is quite probable, that the schist in its actual metamorphic habit represents an original psammitic rock of the arcose type, where the feldspar has contributed to the formation of mica. The mica is in most cases a biotite, oriented in subparallel direction between the quartz grains. Other varieties of he schists contain also sericite, whose relative quantity rises occasionally forming sericitic schists. Garnet of reddish colour also occurs, sometimes quite abundantly, with rounded contours and of granoblastic habit. The whole microstructure indicates a strong recrystallisation, undergone by the rock.

The *mica schists* occupy, as mentioned, principally the broader zones, relatively free from granitic intrusion, but very intensely penetrated with concordant sheets of amphibolite. The most important of these zones runs over the Cerro Villa Union and over the Sierra de Umango ridge with a general NNW-trend.[1] Another zone with heavy amphibolitic sheets occurs in the Vinchina valley ground, exposed on the surface in the Asperecito hills close to Villa Castelli.

The ordinary habit of these schists resembles the alpine „schistes-lustrées" with silverglittering planes carrying abundantly quartz-lenses and garnet aggregations. The schistosity planes are uneven, generally rippled. The amphibolitic layers are strongly concordant in the rock structure. The mica is generally represented by muscovite, but in many parts biotite also occurs, attaining the same relative quantity as muscovite. The last case results in a type, corresponding to a two-mica-schist. Another variety is a sericitic schist of pale greenish colour and with intensely lustering planes. It is garnet-

[1] See fig. 2, pag. 7.

bearing too and very intensely microfolded. The occurrence of this type is quite limited, appearing, as mentioned, only in alternance with quartzitic schists. Microscopically the sericitic schist shows a considerable amount of ferri-oxyde, forming parallel thin zones and very markedly indicating the microfold-structure (see Plate I, fig. 2).

The mica schists are also to be found in various parts of the Umango area as small intercalations between other thin layers in the so called banded rocks, below more closely characterized. The highly granitized areas, as the summit of the Cerro Cacho and in the eastern part of the region, are also represented by mica schists. The mingled product, called by Sederholm migmatite, and also wholly resorbed rocks, appear many times here, as e. g. in the western foothills of the Nevado de Famatina.

According to Bodenbender there are abundantly in the last named mountain in the higher regions, wholly surrounded by granite (cf. the little sketch map, page 30), micaschists with basic intrusive sheets of exactly the same appearance as in the Umango area. They represent metamorphosed, cambrosilurian slates. The writer had occasion to see these schists, as he crossed the mountain on his return journey from the Umango district, and he could prove their similar appearance.

Whereas in the Famatina area there are in some parts but slightly metamorphosed facies of the slates and other sedimentary rocks (the fossiliferous parts), all the sediments of pregranitic age in the Umango area have a very strong metamorphic habit to make it hopeless to find any tracks of fossils or even to meet any possibility of studying the original lithological structures. The changes have been not only of contactmetamorphic nature but also kataclastic in many ways.

If it is correct to consider the easternmost part of the Umango complex, situated nearest to the Famatina granite batholith, as the lowermost horizon, and the western parts generally as crustal masses of a higher position, one may state, with reference to the distribution

of the sedimentary types, that the quartzitic and mica schists occupy the lower, the great limestone banks the higher stratigraphical levels.

The question about the relations of the Umango sedimentary series to the geological structure of the surrounding countries and the problem of the age of these rocks will be treated of below.

Discussion of the Geology of the Umango „pregranitic" sedimentary pile.

As seen, the series are composed principally of *three* types of rocks, representing the three principal members of products of subaerial decomposition by chemical way: *lime, silex* and *argile,* with some transition products especially between the two later. It may be presumed, that the basement of the sedimentation was gradually sinking, because the limestone banks occur in the higher horizons. The continental surface, from where the decomposed material derived, was probably an ancient one, composed of acid silicate rocks, as for instance the old precambrian terranes. It is probable from the heavy masses of quartz-sediments in the Umango area, that many acid rocks really occurred in this terrane. The complete lacking of conglomeratic layers in the Umango series and also of other traces of stratigraphical breaks makes it very probable, that the sedimentation proceeded quite uniformly.

Above was stated, that in consequence of the intense metamorphic changes in the Umango series it is impossible to determine the age of the rocks by way of fossils. One will arrive at a definite conclusion with this question by comparing the Umango rocks with others occurring in the neighbourhood.

Above it was already stated, that the schists of the Umango area show a great resemblance with the similar metamorphic schists of the Nevado de Famatina. Whilst the last are considered by Bodenbender of cambrosilurian age and are intruded by the same granite (the Famatina batholith), both in the Umango and in the Famatina, and older granites do not appear in the Umango, it seems

very probable, that the Umango schists are homotaxial with the Famatina schists.

The great limestone banks in the Umango area are met with principally on the western side, in the Cerro Cacho and on the lower mountains between her and the Sierra de Umango ridge. By studying the map recently worked out by Rassmuss illustrating the Precordillera of the province of La Rioja, one becomes convinced, that the Umango limestones once formed the northward continuation of the mighty lower silurian zones of the said mountain chain. Therefore, the Umango limestones may be of lower silurian age too. The circumstance, that the later are strongly metamorphosed and contorted, whilst the limestone masses of the Precordillera are unmetamorphosed, does not form any obstacle to the presumption, and may be explained by the possibility, that the Umango is forming another structural element in respect to the Precordillera.

Studying the report and map of W. Penck (1920) from the western part of the province of Catamarca, to the north and northeast from the Umango area, one will find that the intensely folded, banded and metamorphosed structure of the Sierra de Umango continues NE- and NNE-ward under the floor of the Jaguel bolson far into the mountains of the western part of Catamarca, an area lying to the west of the valley of Fiambalá. To the east the Catamarca structure is bounded by a granite area, corresponding to the Famatina batholith (which also forms the eastern margin of the Umango structure). The Catamarca structure may be of lower palaeozoic age[1] and undoubtedly it is of the same as the Sierra-de-Umango-element. The limestone is there, however, completely lacking.

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[1] Penck has expressed the opinion, that it is of devonian age, but while fossils are also here lacking, this statement is of no definite character. Nevertheless, no doubt, it is palaeozoic and of pre-Gondwana-age at least (see later on page 61).

The Precambrian Basement.

Above we have presumed, that the sedimentary members of the Umango structure are derived from an old surface, composed probably of chiefly acid crystalline rocks, *i. e.*, a precambrian basement. The next question which arises, is where to find this basement, and if it still exists in this part of the Republic.

The Umango schists are rooting in an irruptive granitic mass, the Famatina batholith. Everywhere to the east the schists are bounded by this granite with its many dikes and embayments. Thence a precambrian complex is not visible here. Going farther to the east, into the Famatina mountains, one meets with complexes of the mentioned cambrosilurian schists, on all sides surrounded by the irruptive granite (see the sketch map, page 30). Here also an older element is lacking. Bodenbender mentions, that the Famatina granite extends eastward to the very foot of the Sierra de Velazco, a mountain mass rising to the east of the Chilecito valley. On the western slope of this mountain an old gneissic rock extends in a northerly direction as already recognized by Stelzner and Brackebusch, and fixed on the map of the latter. The gneiss shows an irruptive contact against the Famatina granite. On the crest of this Sierra we find again the same younger granite (see the corresponding profile of Stelzner), probably only a branch of the great Famatina intrusive body. This old gneiss may probably be regarded as the precambrian basement. A confirmation of this statement will be found in the relations further to the north, in regions of the province of Catamarca. Here is found a mountain system to the east of the above named valley of Fiambalá, more closely investigated by W. Penck. This terrane consists of old schists and gneissic rocks with younger granitic intrusions as in the Sierra de Velazco. Between the schists-gneisses and the western element, i. e., the continuation of the Umango structure, there occurs a large granitic body, according to Penck, belonging to the Famatina batholith.[1]

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[1] See the map of W. Penck (1920).

The old rocks to the east of the valley of Fiambalá are again divided further to the east by granite from an extensive, precambrian terrane in the Sierra del Aconquija mountain complex, studied by Rassmuss. This last named precambrian shows to the east a marked unconformity against a still older gneissic complex, regarded by Rassmuss (1916) as archaean.

The great Famatina—Fiambalá intrusive body of lower palaeozoic age seems to form a kind of *interformational* batholith between the Umango structure to the west and the precambrian gneisses to the east. One may assume, that the Famatina intrusion was cutting off the connections between the lower palaeozoic structure and its basement, so that an unconformity between these two elements may probably never be found here.

b) THE BASIC INTRUSIVE (AND EFFUSIVE?) ROCKS (METAVOLCANICS).

The very abundant intercalations of basic schistose rocks between the doubtless sedimentary schists are characteristic members of the „pregranitic“ schist complex of the Umango area too. These basic rocks are partly ordinary amphibolites, according to the definition given by Rosenbusch, partly of different aspect and almost difficult to be classified, because of the intense kataclasis undergone by the rocks. But it may be assumed, that the greater part of these dark schists represents igneous (partly gabbroid) injections into the sedimentary schist masses. These injections appeared already at a time, when the sediments still lay in their original position, i. e., before the first palaeozoic diastrophic movements and before the intrusion of the Famatina batholith took place. The basic rocks are therefore „pregranitic“ too.

The original relations between the sedimentary schists and the basic sills have been destroyed at different times to a considerable extent. The thin layers and lenses of amphibolite in the limestone masses are certainly in most cases only the remnants of thicker volcanic sheets, afterwards, during the folding movements, extremely

thinned out and torn. The banded appearance of the amphibolites in the granitic injection zones of the more central parts of the area, — as will be demonstrated later on — a very common phenomenon, is produced principally by an exfoliation-process of thicker amphibolite layers by way of concordant granitic injection. Only in the zones of the „schistes lustrées" the amphibolite sills occur in a more preserved stage, a fact due principally to the almost complete absence of granite veins. An exception from this rule is to be found in the hills of the Cerro Asperecito, the Cerro Pintado and the Cerro Tupe in the Vinchina valley, where the amphibolite layers are intensely penetrated as to form an arterite (Sederholm), due to the immediate vicinity of the Famatina batholith. But the appearance as a whole, the concordant alternance between the schists and the sills, is still conserved here too.

On studying the microstructure of the basic rocks, it is seen, that hardly in anyone part of the area a primary or an almost primary one occurs. The structure is either a kataclastic or a recrystallized one, because undergone all diastrophic movements of different times. The basic rocks may here be divided into three groups, as follows:

1) Concordant sills of amphibolites.
2) A peridotitic sill rock (local occurrence).
3) Basic, kataclastic schists of doubtful origin.

Tho these belongs still an isolated type of porphyritic character and of local occurrence too. While the rock is of less basic character, it will be described apart from the enumerated types.

1) Concordant sills of amphibolites.

The greater part of these amphibolites occurs, as mentioned, as mighty, alternating sills in the mica schist zones, where they often appear with astonishing regularity. They are also found in the quartzitic schist masses and in the limestone banks, where the sills are generally thinner. The contorted appearance of the limestone has already been mentioned.

All these intercalating basic layers are, as stated above, very strongly metamorphosed (corresponding to the „metabasites“ of Hackman). The metamorphism was either of purely plutonic character, or a result of dynamic influence during later diastrophic periods. The original petrographical character is therefore very difficult or impossible to approve, regarding the circumstance too, that chemical analyses are still lacking. It seems probable, that the original geological appearance of these rocks are for the most part basic intrusions or sills of diabasic or gabbroid kind, from a time anterior to the orogenetic movements and granite injections.

In order to carry on a deductive petrographical study of these rocks it is necessary to go to the neighbouring regions, where there are better conditions for such a study. Observations in this respect are, however, still lacking. The occurrence of cambrosilurian fossiliferous slates, slightly metamorphosed, in the Nevado de Famatina seems to offer a favourable possibility to discover tracks of the primary structures in the basic sills.

The secondary structure of the „metabasites“ of the Umango area is partly of granoblastic habit, due to a complete recrystallisation under abyssal conditions, partly of a crystalline schistosity, caused by a stress influence under contactmetamorphic conditions. In some parts are found also purely kataclastic types.

The amphibolites have undergone a complete recrystallisation and developed a granoblastic structure, especially in the vicinity of pegmatitic veins of larger size, where pneumatolytic action has favoured the former. The types may be described going from east to west.

The above named amphibolite layers in the Cerro Asperecito, situated in the bottom of the Vinchina valley, near to Villa Castelli, are intimately penetrated with small granitic veins and also larger apophyses, and therefore they ought to be completely recrystallized, but a later pression (apparently tertiary movements) has caused a kataclasis. The principal minerals are amphibole and plagioclase, the first named generally developed in individuals of greater size than

the plagioclase. The amphibole shows in the prismatic zone a maximal extinction angle of nearly 20°, the normal one of ordinary amphiboles. The pleochroisme varies between grassy-green and greenish-yellow. The prismatic cleavage is well developed. The plagioclase is highly granulated by the dynamic influences, forming relatively small allotriomorphic grains. Albitic twinning lamellae are not well developed, so that measures of the extinction angles were difficult to realize. Biotite is a more accessory constituent. It is, hovewer, visible in handspecimen. Quartz is very scarce. The rock structure as a whole is distinctly schistose, because the amphibole individuals have been broken up in elongated fragments, following the prismatic cleavage. These fragments have also been arranged in subparallel lines. It may be mentioned, that the c-axis is parallel oriented to the general schistosity planes and also the biotite flags. The plagioclase grains are independent of the schistosity and form a finegrained matrix between the elongated constituents.

The crystalline hills of Las Ramaditas on the eastern side of the Cerro Villa Union show, that the amphibolites play here a very important part, forming whole hills and ridges. The dark masses of this rock are distinctly crossed in various directions by granitic and pegmatitic veins of red colour, representing a typical apophyse zone of the Famatina batholith (see later on). The amphibolite is here always highly recrystallized with a well developed parallel structure. The sills lie concordant between quartzitic and thinner limestone layers.

Near to the west from the Vinchina valley too, on the eastern slope of the Cerro Potrero Viejo,[1] where banded rock complexes predominate, the amphibolite layers are very abundant, playing an important part in the mentioned banded structure. The amphibolite is of a thinner appearance, because of the concordant penetration with granite veins. The rock is not only recrystallized, but also partly absorbed (lateral banding by assimilation, a phenomenon described later on).

[1] Also named Cerro la Pampa.

A microscopical slide of the not assimilated rock shows, that the principal minerals are plagioclase and amphibole. The first named is very altered by sericitic growth, and it is impossible to determine the extinction angle on oriented sections. The amphibole has a maximal extinction angle of little more than 20° and may consequently be of the ordinary type. The absorption scheme is the usual too. Small grains of poikilitic quartz occur in the amphibole individuals. Iron ore is present as small grains thinly scattered through the rock mass.

The abyssal body of the southern part of the ridge Sierra de Umango, called Cerro Cordobés (also Cerro Guecito), contains very abundantly metamorphosed amphibolites. The rocks occur often as isolated rootless masses in the granite body, but interstratifications between sedimentary schists also exist. A handspecimen of an amphibolite of the latter kind from the contact with granite shows a kind of porphyritic structure, by small spots of a pale mineral contrasting with the dense dark mass. U. M. the spots or „phenocrysts" consist of aggregates of a very dull feldspar. The dark mass is composed chiefly of a green pleochroic amphibole and also of minute feldspar grains. Grains of iron ore are abundantly dispersed throughout the rock mass. The feldspar aggregates often contain garnet individuals of reddish colour in their centre, indicating that a recrystallisation of the rock has taken place.

An amphibolitic type of a somewhat different composition occurs as an isolated sheet in a „promontory" or rock cape on the way between Maz and Villa Union, i. e. on the marked northeastern corner of the cerro Villa Union. The rock is characterized by a brilliant lustre and an almost black colour on the surface. It forms a vertical sheet holding red granite on both sides. Already in handspecimen the rock shows a monomineralic composition, an impression confirmed by the microscopical investigation. The mineral is a dark green, intensely lustering one of the amphibole group. Schistosity is not developed in the rock, and the whole structure lacks

every sign of pressure. The amphibole shows the following microscopical properties: The colour is very pale greenish — grayish, a somewhat astonishing fact regarding the almost black aspect of the rock surface. The absorption is very slight, and observable only in orientations parallel to the c- axis. The amphibole-prismatic-cleavage is well developed. The refringence is high and also the birefringence. The optical character is +. According to the measurements of the angle of extinction, attaining 21 °, the amphibole seems to be a variety of pargasite and the whole rock perhaps a product of metasomatic limestone replacement. Quartz is visible only in small quantities.

The mighty zone of „schistes lustrées“ in the higher part of the western side of the Sierra de Umango ridge contains, as has been mentioned, a great number of concordant, regularly alternating sills of an amphibolite schist of some ten meters of thickness. No smaller ramifications or thinner layers occur besides. The appearance is the same as in the Asperecito Hills in the Vinchina valley, but granite veins are not existent here disregarding a broad granite zone on the very crest line of the ridge.

The rock has a marked schistosity, and the schist planes are covered chiefly with amphibole individuals of an almost black aspect. On transverse ruptures the rock seems rich in salic minerals, but the whole appears as a kataclastic mass. Microscopically (transverse cut) one find an extremely crushed structure, formed principally from the breaking off of the feldspar minerals. Also the amphibole has been dissolved into fragments along the lines of prismatic cleavage and forms subparallel lines of grains. The amphibole has quite a marked absorption and seems to be of the usual kind. The feldspar grain-mass carries a small amount of quartz too. The size of the grains is variable. The larger ones consist of a plagioclase. The mineralogical composition of the rock seems to correspond to a quartz bearing diorite, once concordantly intruded into the schist mass. Regarding the high amount of later kataclastic metamorphose, see later on (page 55).

2) Peridotitic rock (sill).

In the eastern part of the group of hills called Las Ramaditas and situated to the east from the Cerro Villa Union, there occurs at the foot of a red sandstone ridge in the crystalline basement a black, coarse grained rock of quite a massive character and running as a sheet concordantly between steeply inclined quartzitic schists.

Fig. 4. Peridotitic, serpentinized rock. The upper part is pyroxene, the lower serpentine and ferri oxyde. Nic. 11. Magn. 120 × Las Ramaditas.

The whole complex is intruded with red granite and pegmatite dikes. In handspecimen the rock is of a coarse granular habit with a black, brilliant mineral as a dominant component. The massive aspect of the rock is remarkable, regarding the circumstance, that the other pregranitic rocks show stress influences.

Microscopically the specimens (see fig. 4) show a peridotitic rock consisting of pyroxene and olivine, both colourless in the slides, but both also partly transformed to green-yellowish ser-

pentine. The olivine is more intensely altered, often showing only small residuals in a mass of serpentine. Except the last mineral, there are as secondary product ferri-oxyde, forming a kind of network in the serpentine mass and doubtless marking the former cleavage of the olivine individuals and also the limits between themselves. The pyroxene has partly a well developed prismatic cleavage. Where this cleavage lacks, it is not always easy to distinguish the two colourless minerals from one another.

The ordinary amphibolite rocks in the vicinity (Las Ramaditas) are all very schistose. The peridotite lacks all signs of pressure because of the circumstance, that the rock is profoundly altered by serpentinization and because limestone layers in the immediate vicinity have formed a more plastic resistance during the diastrophic pressure.

Other rocks of a similar kind are not found in the Umango „pre-granitic“ series. The described occurence seems therefore to be only a limited one.

3) Basic, kataclastic schists of doubtful origin.

In the Umango area there are in many parts intercalations of „dark schists“ between the sedimentary schists differing from the amphibolitic schists. Megascopically they show kataclastic secondary schistosity, and the original petrographical character is generally very difficult to decipher. All these rocks offer very excellent examples of kataclasis, as will be shown below.

Many of the types in question have a porphyritic habit. Examining them more carefully, one finds, that this structure is really a porphyrokataclastic one, the larger minerals are only remnants of larger original grains, while the „groundmass“ is represented by finely crushed rock. The orientation is that of dynamic flow. In some cases the schistosity originated at an earlier date than the intrusion of the latest (white) granite, and the rock is therefore in some degree recrystallized.

B) THE FAMATINA GRANITE INTRUSION AND ITS EXOGENE PLUTONIC METAMORPHISM.

The Famatina Batholith.

The great intrusive body of the Famatina granite, belonging no doubt to a very important group of lower palaeozoic granitic unities

Fig. 5. Part of the Famatina batholith, including cambrosilurian schists (black). Shaded: fossiliferous parts. The area covers the Nevado. Scale about 1:700,000. Copy of the map of Bodenbender. Later formations not signed.

in the pampean sierras-area, has as most of the other similar bodies been laid bare by the erosion to a great extent. This fact is evident by the study of the geological map by Bodenbender (1916) on the Nevado de Famatina, of which here is reproduced a small copy, showing only the relation between the granite and the in-

cluded palaeozoic schists (see fig. 5.) The approximative actual extension of the batholith in the surface is, as follows: to the west the body is bordered by the Umango schist area; to the north it extends far into the mountains surrounding the valley of Fiambalá, in the province of Catamarca, a fact proved by Penck (1915), but shown already on the map by Brackebusch (1891). To the east the granite body reaches probably to the western foot of the Sierra de Velazco, although, according to the map by Brackebusch, there seem to be outcrops of parts of the gneissic rocks already in the valley hills of Chilecito. According to the map of Bodenbender (1901) the granite extends far in the southerly direction.

Completely surrounded by this granite lies, as the map (see fig. 5) shows, a complex of metamorphic schists, mica schists, quartz schists and amphibolitic schists etc. The sedimentary components are in some parts but slightly metamorphosed and do carry fossils here (Kayser 1876). The whole complex is therefore considered by Bodenbender (1916) of cambrosilurian age. Besides these fossiliferous parts of the mass of schists, one generally meets a strong metamorphism, attaining its maximum on the western foot of the mountain, where mingled and resorbed rocks lie in a mass of pure granite. At the western wall of the Vinchina valley the plutonic metamorphism is of a similar intensity as in the Umango schist complex. These phenomena will be treated of in a following chapter.

Generally the geological appearance of the Famatina intrusive body has an abyssal habit, exposing irregularily contact lines as a result of a mingling and intense injection of apophyses. Similar deep seated granitic cores now exposed by the erosion occur in many parts of the pampean sierras-areas. Already on the map of Brackebusch (1891) a greater part of these granites are marked with „rocas eruptivas antiguas“. It cannot yet be stated, if they are all of nearly the same age, but in many cases a lower palaeozoic age has been presumed. In the Sierra del Aconquija

Rassmuss (1916) has investigated a granitic body of abyssal appearance, penetrating a complex of precambrian schists, considered by him to be of a lower palaeozoic age. The shape of the body is probably that of a batholith with overhead stoping phenomena and a remnant of the roof still visible.

It is necessary to carry on a detailed petrographical investigation of the different granitic types of the Famatina batholith and their exogene metamorphic products. The recent communications by Bodenbender (1916) embrace principally stratigraphical observations, and as to myself I had but little occasion to collect specimens here. I have studied in some degree only the western foot of the Nevado, or the eastern border of the Vinchina valley. In the following pages I will give a petrographical description of the probably most important types, collected on the western side and also in some parts of the Sierra de Sañogasta. The plutonic metamorphism as concerning the Umango area has of course been studied with greater attention.

a) GRANITE VARIETIES OF THE FAMATINA.

During my excursions in the batholith area I got the impression, that the whole body has quite a uniform composition, at least concerning the Nevado de Famatina and its southern prolongation, the Sierra de Sañogasta. The most usual type seems to be a *medium-grained, reddish or grayish biotite granite*. Amphibole bearing varities also occur. The structure lacks a parallel orientation, and porphyric development seems to be quite scarce. The reddish types are often acid or almost aplitic. In the last case a sharper contact with other types may be observed.

The *biotite granite,* which Bodenbender (1916) mentions from different localities, seems to be, according to my observations too, of a wide extension. The colour of the rock varies between reddish and gray.

A handspecimen of this type from the Quebrada de Tambillos,

on the western slope of the Nevado, shows a medium grained habit, without traces of kataclasis and of a reddish colour. Mafic minerals are met with to a very small degree. Microscopically the structure seems to be a panallotriomorphic one, with regard to the contours between the quartz and feldspar constituents. The feldspar is an orthoclase, but generally with a perthitic development showing a kind of undulating extinction. This circumstance indicates, that the perthite probably is of secondary, dynamic origin („dynamic perthite"). Plagioclase is found only in a small degree having a zonar structure with transitions between the different zones. Of mafic minerals one finds only biotite in small spots and also minute grains of iron ore. The rock structure as a whole seems to have quite a slightly altered consolidation habit, where dynamic influence is shown only by „undulating" perthite.

Another handspecimen from the Sierra de Sañogasta, on the road from Puerto Alegre to the Sañogasta village, shows a reddish aplitic type with quite large grains of somewhat unequal size. The microscope (see Plate II, fig. 1) shows a very distinct inhomogeneous structure: small grains mingled with larger ones of allotriomorphic habit. The principal constituents are a reddish, pigmented potash feldspar and quartz. By greater magnification one finds the feldspar composed of a cryptoperthite. In some parts of this mineral there are small rounded inclusions of albitic plagioclase, poicilitically penetrating the perthitic structure. Also small quartz grains of similar appearance may be observed. These last named ones show a common optical orientation over greater spots. The structure of the rock has still a fairly primary habit, while only the feldspar seems to have been broken up to some extent, but this might also be a protoclastic phenomenon, so also the aspect of the quartz mass, which is clear and fills up all the sinuous spaces of the feldspar individuals.

A second handspecimen from the Sierra de Sañogasta of a reddish gray biotite granite of coarse, but inhomogeneous grain, con-

tains biotite megascopically visible in small torn spots, irregularily scattered through the rock mass. Microscopically (see Plate II, fig. 2) there are proofs of a strong kataclasis, with the most intense granulation of the quartz component, the last as a kind of cement filling up the spaces between larger fragments of feldspar. This latter mineral is viz. lesser crushed than the quartz, an usual phenomenon of the kataclasis processes of quartz-feldspar rocks. The dynamic influence is also shown by the development of an undulating extinction of the feldspar, frequently in association with „undulating perthite", especially in the more elongated corners of the mineral. Generally it seems to be a plagioclase, although a closer determination is impossible. Mafic minerals are present to a small extent, essentially minute biotite spots.

This extremely crushed granite seems to be very common in the Sierra de Sañogasta, and also in other parts of the granite body according to the observations of Bodenbender (1916). The corresponding dynamic processes probably occurred during the tertiary diastrophic periods.

In the above mentioned Quebrada de Tambillos on the western slope of the Nevado I discovered also a finegrained aplitic type. The quartz appears in handspecimen dark and well individualized, and the feldspar has a reddish colour. Mafic minerals seem to be completely absent. No microscopical examination were made of this rock. It develops distinct contact lines to the surrounding types of granite, and may perhaps be of a somewhat younger date.

Regarding the occurrences of porphyric varieties in the batholith Bodenbender (1916) mentions a quartz porphyric type from the highest part of the Nevado. I know also such specimens from my route over the Pampa and Tocino passes. Their occurrences may possibly correspond to a higher crustal horizon, because there are in the vicinity fossil bearing rocks of the intruded schist mass.

A granite type with great feldspar phenocrysts (granite-porphyry) extends over some wider areas on the eastern part of the intrusive

body, outcropping in a series of hilly ridges between Paiman and Chilecito (see the map by Bodenbender, 1916). This type may merely be regarded as an abyssal facies, where the consolidation proceeded in some other way.[1] The groundmass of the granite-porphyry is viz. of a coarse grain (normal granitic structure). The phenocrysts, measuring some cm in length, are orthoclase. They show a tendency to idiomorphic development. The other components are quartz, oligoclase-andesine, microcline, apatite, zircon, etc. (Bodenbender). There are seldom pegmatitic differentiates. According to Bodenbender this type dominates also in the region of La Aguadita (between Los Angulos and Famatina). To the west the rock changes evidently into a more normal granite.

As far as I have observed, the batholith generally seems to carry but few xenoliths except the large schist bodies in the upper parts of the Nevado. Only in some localities on the road between Puerto Alegre and Sañogasta I have noted the occurrence of a dark, quartzitic rock forming breccia floating in the homogeneous granite mass. But approaching the western border of the batholith, i. e., the eastern margin of the Sierra de Umango schist-area, there is, especially in the foothills of crystalline rocks, extending along a line between Villa Castelli and Villa Union, a marked zone of mingling and brecciation phenomena treated of in the following chapter.

b) THE ZONE OF ABYSSAL MINGLING, BRECCIATION AND ASSIMILATION ON THE WESTERN BORDER OF THE FAMATINA BATHOLITH.

Phenomena of plutonic metamorphism in a gigantic scale are well exposed in the foothills at the western slope of the Nevado and continue under the bottom sediments of the Vinchina valley until they appear again in the hills, belonging to the Sierra de Umango-mountains. The metamorphic products, occurring on the eastern side of the valley, are, however, of a special character, due

[1] The phenocrysts may represent the exceeding part of an „anchieutectic“ granitic-magma-mixture.

to the immediate vicinity of the batholith, so that they may more conveniently be treated apart from all the other metamorphic rocks, occurring in the Sierra de Umango area.

The foothills of the Nevado are rugged, completely barren ridges of more longitudinal extension. They rise abruptly over the extensive mountain gravel plains and are separated from the granitic slope of the Nevado by similar gravels. The best exposures are to be found opposite the village of Villa Castelli, in the Cerro La Vatea (Batea) (not visible on the map, fig. 5).

The Famatina granite has in this locality penetrated into and dissolved a complex principally of mica schist and amphibolite. In accordance with the general northerly orientation of the Umango schists the inclusions of the Nevado foothills show the same strike, in spite of the intense mingling with granitic material. Irregularities have been developed more in details.

The manner of intrusion depends on the lithological character of the penetrated rocks. The mica schist has generally been intensely exfoliated along the schistosity-jointing-planes and verbally penetrated with granitic „blood". This process was accompanied by an intricate folding on a small scale indicating a plastic stage of the rock mixture, a contortion without fractures. This phenomenon has been called by Sederholm [1] „ptygmatic folding", a very characteristic feature in the deeper archaean terrane in Finland and elsewhere.

The amphibolite has mostly been shattered into great eruptive breccias with a matrix, composed of acid differentiations from the granitic magma, a very common phenomenon in every such case of injection. [2]

[1] J. J. Sederholm: Ueber ptygmatische Faltungen. Neues Jahrbuch für Mineralogie, etc. Beil. Bd. *36.* 2 Heft. Sept. 1913. Page 491.

[2] Adams and Barlow: The Geology of the Haliburton and Bancroft Areas, Province of Ontario. Canada. Dept of Mines. Geol. Surv. Branch. Mem. *6.* 1910.
J. J. Sederholm: Om granit och gneis. Bull. Comm. Géol. de Finlande. N:o *23.* Helsingfors 1907. With an english summary.

The injection process was not only limited to a mingling of the granite magma with the schist mass. There are also on a gigantic scale the signs of an *resorption*, in the extreme cases conducing to almost homogeneous rocks of different composition. Naturally all stages on the way to a complete resorption may be observed. The mica schist passes into a dark gneiss of quite a homogeneous habit, and the amphibolite breccias are gradually dissolved into a chaotic mixture, or „stew", of resorbed or partly resorbed xenoliths and granite. The extremely resorbed amphibolite or, more correctly, a basic secondary granite magma, has, as stated later on, a considerable extension in this zone.

The incompletely absorbed masses, the inhomogeneous mixtures show often a roughly parallel structure; the fragments and the almost resorbed spots are oriented in common direction, indicating, that the whole mass was in a flowing motion before consolidation. Also the completely absorbed masses develop in some cases flow structure.

Petrographical characteristics.

The petrographical description of this zone may begin with the amphibolite and its metamorphic products, because they play the most important part in the general composition of the zone.

The great *amphibolite breccias* show often the unchanged amphi bolite without other signs of the granite action, but a complete recrystallisation. The fragments are angular and often of a considerable size. The contours are sharp against the matrix, which is a pegmatitic, pale coloured granite, carrying isolated amphibole and epidote of greater size. The structure of the rock fragments is granoblastic and often coarse, and towards the edge the grains increase in size, probably by influence of the pegmatite matrix. The borders are therefore not seldom on the rock surfaces marked with a black fringe (great amphibole individuals).

The principal minerals[1] are feldspar, very altered, probably always plagioclase, and amphibole of ordinary habit. The plagioclase forms partly porphyroblastic phenocrysts, with extinction angle on cuts perpendicular to M and P corresponding to $Ab_{60}An_{40}$. The contours of the mineral components are generally sinuous. No tracks of pressure are visible, and it is possible, that the rock after some earlier crushing process has undergone a complete recrystallisation with a hornfels structure. Iron ores in minute grains are scattered over the whole rock mass. Also biotite is present, showing strong absorption and an intimate association with the amphibole. It is highly probable, that the biotite is only a metasomatic product of the amphibole, originated by influence of the granitic magma. This phenomenon will be treated of at an another occasion later on. All stages of transformation of amphibole to biotite are represented, and the extremely dissolved breccias show fragments wholly composed of biotite rock.

The last product of the assimilation process of the amphibolite by granite is quite a homogeneous rock of true magmatic aspect, a *syntectic diorite*. This rock was already observed by Bodenbender and sometimes called by him „tonalite".[2] It is surprising wide spread in the present rock surface of the foothills. It forms the principal rock of the zone.

This remarkable rock is gray in colour, of large grain and quite rough, and its surface weathers in a peculiar way, forming small kettles and hollows, like results of a desert deflation. Dark inclusions of mafic mineral aggregates are common. By its whole appearance the rock is well distinguishable from the ordinary Famatina granite. Contact lines between these two have not yet been studied.

Regarded from a closer distance or as handspecimen the dioritic

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[1] See the Plate III, fig. 1.

[2] According to Bodenbenders handspecimens from the Nevado, kept in the Museum of the Direction of Mines.

rock shows a remarkable inhomogeneity due to the appearance of biotite spots of irregular size and distribution. Somewhere the biotite concentrates to greater streaks or *Schlieren*. These are, as was stated above, often subparallel, evidently by flow during the consolidation. Microscopically the rock is quite quartz-bearing. According to measurements of the angle of extinction in cuts perpendicular to M and P of the principal mineral, a white plagioclase feldspar, it has the composition $Ab_{60}An_{40}$. The chief mafic component is, as has been stated, a biotite with a strong absorption. This mineral is frequently penetrated with poicilitic grains of quartz, with common areal optical orientation. The border zone between the feldspar and the quartz develops a myrmekitic intergrowth. The structure of the rock is, however, in general allotriomorphic. Only small scattered apatite individuals show idiomorphic forms. The quartz is of jagged contours, probably due to recrystallisation, while traces of pressure are not visible. Amphibole occurs to a reduced quantity as insignificant individuals. The biotite is partly transformed to an opaque mass. Iron ore also occurs in minute spots.

Aside from the basic concentrations (biotite bearing masses) in this rock there are numerous acid *Schlieren,* apparently real differentiation products of the syntectic magma. These acid varieties are of a pale red colour and have no precise limits towards the main rock. The shape of the *Schlieren* is irregular and may be kept apart from the crosscutting pegmatite dikes of the last eruption phase of the batholith, described below.

To the west, towards the Umango schist body, the syntectic, quartzbearing diorite shows a marked irruptive contact, well visible in the Asperecito hills to the west of Villa Castelli.

A dark gneissic rock, occurring as quite a long zone in the abrupt western slope of the Cerro La Vatea, is very probably of syntectic origin too. In handspecimen the rock seems to be more a basic granite with a marked parallel structure, visible on the rock-

surface. The fact, that the rock in question appears in localities, where the mica schist is most intensely penetrated with granite, makes it probable, that it is a product of complete absorption of the named schist. — The microscope reveals the following mineral composition: the feldspar is partly a microcline, partly a plagioclase of ordinary, dioritic habit. A biotite with strong pleochroism is abundant and partly transformed to a fibrous substance, showing a high refringence and birefringence. Its colour is transparent, light pale brownish. The mineral is evidently the sillimanite-variety called fibrolite. Also muscovite is visible, almost invariably associated with biotite. — The structure of the rock is generally evengrained without signs of kataclasis. Only the fibrolite has partly a dynamic flow arrangement as shown on microphotograph (Plate III, fig. 2). The transformation of biotite to fibrolite is very probably a dynamic phenomenon too.[1]

c) CROSSCUTTING PEGMATITIC DIKES.

The Famatina last injection phase.

The sharply crosscutting, broad pegmatitic dikes here are younger than all the mingled and molten rocks in the abyssal zone on the eastern side of the Vinchina valley. Doubtless they due their origin, however, to the Famatina injection process and form its last „acid“ phase, because of the fact, that the dikes show transitions to the ordinary aplitic granite. The crosscutting character and the conspicuously flat lying position of them indicate, however, that there must be a hiatus between the principal intrusion act and the eruption of these apophyses; in other words, that there was already a

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[1] The principal occurrence of *sillimanite* is, as known, in exogene contact rocks and also as inclusions in a granitic magma (Cfr. Adams and Barlow, l. c. page 131 a. o.). The typical development of *fibrolite* is, according to Rosenbusch (Mikr. Phys. der Min. u. Gest. Teil II. Stuttgart 1905. Page 137), in the form of a dynamic transformation product of biotite. In the present case no simple contact influence has produced the alteration because the very rock is an syntectic one. The dynamic process is probably of tertiary age.

stage of beginning consolidation in progress, when the pegmatitic dikes cut through the zone in question.

These dikes, broad and light coloured, very markedly visible in the rock ground, are highly differentiated. The border zones are formed of a red feldspar and the midst of the dike is filled with milkwhite quartz. Frequently there is also a smaller exterior border outside the feldspar mass consisting of an evengrained aplite. The limits between the feldspar and the quartz masses are quite distinct. The thickness of the dikes varies much and attains several times some meters. It may be noted, that the differentiation appears with the same distinction in dikes of various breadth.

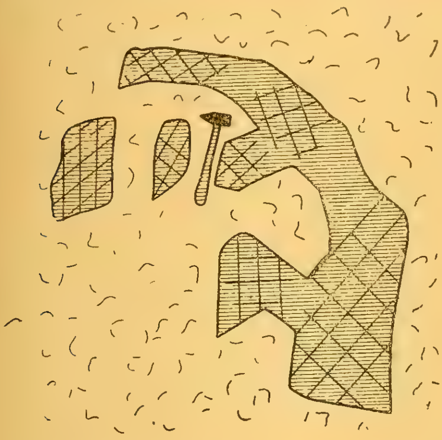

Fig. 6. Great individuals of red potash feldspar lying in a milkwhite quartz mass. The cleavage tracks of the feldspar are visible. Hammer shaft about two decim. Pegmatite dike NE from Villa Union.

The quartz mass contains often well developed crystals of a black tourmaline (schorl). The feldspar is a red orthoclase and forms, when isolated, great individuals (see fig. 6), never mingled with quartz. The habit of these individuals is idiomorphic in some degree, showing partly the pinacoids well developed. Pneumatolytic minerals are scarcely existent, except the above named tourmaline. Beryl was once found in a pegmatite and was of greater dimensions with the prismatic faces striated (Cerro La Vatea).

The flat lying position of the dikes is difficult to explain with regard to the general steep inclination of the schists intruded with granite in this zone. The pegmatitic eruptive material has apparently followed independent fissures, opened subsequently to the consolidation of the mingled-rock-zone.

The origin of pegmatites has been regarded, as known, partly as

plutonic, partly as „neptunic".[1] All transitions between these two have been found as well. Keyes[2] in his paper on the Maryland acid eruptive rocks distinguishes between intrusion- and separation-pegmatites. A similar division was also pointed by Holmquist.[3] Regarding the Famatina granite-pegmatites above described, they are all of a purely plutonic character, because they always form typical apophyses, crosscutting or following the schistosity planes of the older rocks. The circumstance, that the pegmatite dikes near the batholith show an extreme differentiation of the quartz and feldspar components, may be explained by assuming the assistance of katalytical gases, causing greater molecular mobility at the beginning of the consolidation.

d) PLUTONIC METAMORPHISM IN THE SIERRA DE UMANGO SCHIST-BODY.

The western sector of the Famatina batholith injection aureole.

It has been stated above, that the Famatina batholith is to a great extent exposed in the surface by a deeply cutting erosion. The consequence of this fact is, that also the cut through the aureole must be of a considerable breadth. A part of this aureole forms to the west the Sierra de Umango schist- area with its innumerable granitic and pegmatitic dikes. In peripherical direction (to the west) it cannot be stated any decreasing intensity of the exogene contact influences, because the aureole is on this side cut off by a great fault. Also later intrusions have altered the succession of the contact zones referring to the batholith. Almost a similar intensity of plutonic metamorphism dominates thence the whole area, except

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[1] C. R. van Hise: A treatise on Metamorphism. U. S. Geol. Survey. Monograph *47*. Wash. 1904. Page 720 and foll.

[2] C. R. Keyes: The origin and relations of the Central Maryland granites. U. S Geol. Survey. Ann. Rep. XV. Wash. 1893—94.

[3] P. J. Holmquist: The Archaean Geology of the Coast-regions of Stockholm. Geol. Fören. i Stockholm Förhandl. Band *32*. Häft. 4. 1910. (Also Guide N:o 15 of the Int. Geol. Congress, Stockholm 1910.) Page 801 and foll.

some apparently downfaulted schist-zones, where granite is lacking. These zones belong probably to a higher crustal horizon.

The degree of metamorphism in the Umango area never reaches the intensity of the abyssal phenomena as in the above described zone on the very border of the batholith, although smaller assimilations also occur here and there.

In the following pages only the products of the Famatina injection will be treated of, while all the cases of alterations caused by a younger granite-syenite will be described afterwards.

The Famatina granite appears in the Umango schist body principally as crosscutting or concordant dikes of red granite aplite or pegmatite *without* differentiation. In some parts we find also broader zones of aplitic granite between the schists, showing at its borders small assimilation phenomena.

The eastern mountain slopes of the Umango area form a zone of some different character, compared with the zone to the east, at the foot of the Nevado. The schists are in the above named slopes not yet dissolved from their mutual connection, and the strike is in detail but slightly disturbed. Melting phenomena are of quite a limited extent. The granite appears here as crosscutting dikes, running in several directions. Only to a smaller extent a parallel injection may be observed. The dikes are of two petrographical kinds: red, evengrained aplite and red pegmatite, the later of an eutectic structure. These are more important and mightier than the aplite apophyses.

The *pegmatites* are of a crom red colour and show no complete differentiation in the quartz- feldspar components. The fact that these pegmatites are „graphically" developed, indicates some different conditions of consolidation than those in the zone nearest to the batholith, where katalytic gases and a slower cooling formed favourable conditions to the development of a zonar arrangement of the components.

The feldspar in the graphic pegmatite is of backstone red colour

and has brilliant lustering cleavage surfaces, where one may observe the presence of small facets. Microscopically are seen, that these facets find their explanation in the structure of the mineral itself. The principal part of the feldspar is orthoclase in cryptoperthitic intergrowth with albite. In this mass there are zones of microcline with transition to the cryptoperthite. These microcline zones seem to be the result of a pression, identical with the „undulating extinction" in the pressed quartz. This kind of secondary microcline might be called „dynamic microcline".[1] The quartz component of the pegmatites is always very clear and shows rounded contours against the feldspar. In spite of the signs of dynamic affect in the feldspar no pression phenomena are observed in the quartz.

The red granite apophyses, consisting of an evengrained aplite, are, as said, of a more reduced breadth. They are contemporaneous with the pegmatite dikes and show in parts transitions to them. The principal occurrences of the aplite dikes are in the mentioned zone of the eastern slopes of the Umango mountains, especially in the hills of Las Ramaditas. The structure of the aplite is but slightly crushed. Where the dikes cut across a limestone layer, a small contact zone of „skarn", i. e., garnet and epidote, may be observed. The intruded quartzitic layers contain red garnet in smaller individuals.

In the crystalline rock-hills of Asperecito (to the north) are found pegmatitic dikes of considerable size, and also aplite. The pegmatite is very rich in muscovite, partly crystallized in sphaerical aggregates, partly in the form of greater sheets, exploited in past times. Turmaline (schorl) is also present here. Magnetite occurs in smaller well developed individuals.

To the west, up to the higher mountains, the pegmatite-

[1] About the formation of secondary microcline see: A. Harker: Natural History of Igneous Rocks. London 1909. Pages 259—260, and J. H. L. Vogt in Tschermaks Min. u. Petrogr. Mitt. (2). Vol. XXIV. Pages 537—541; an interesting application is to be found also in the paper of H. L. Alling: The mineralogy of the feldspars. Journ. of Geol. *29.* 1921. p. 275.

aplite dikes, especially the crosscutting ones are getting more scarce, and in some schist-zones red granite is completely lacking. But in some other parts there are, however, not dikes, but whole zones of red granite. Also real bodies of granite of this kind appear, giving an abyssal character to the locality. Such strongly granitized areas to the west are: Cerro Cordobés, Cerro La Pampa (northern part of the Cerro Potrero Viejo) and the western slope of the Cerro Cacho, down to the tertiary fault line at the Cordilleran border. In the last named area there are also porphyric varieties, but the dominant rock is a red granite.

The structures of all these granite bodies are not described here, because they are almost crushed by later movements, and these phenomena will be treated of later on (pag. 50 and foll.).

C) AN EARLY PALAEOZOIC REGIONAL METAMORPHISM, SUBSEQUENT TO THE FAMATINA INTRUSION.

In the Umango area there are signs of orogenetic disturbances accompanied by an intrusion of a white granite-pegmatite and syenite of apparently younger date, than the Famatina intrusion. The above mentioned white eruptives cut across the red granite in marked dikes, although the most common appearance of the former is a parallel banding in the schists to the west, apart from the Famatina batholith with its network of apophyses. Simultaneously with this younger intrusion a lateral pressure (stress) occurred, causing folds in the limestone banks and also a marked banding over broader zones between amphibolite and other schists and concordant dikes of white granite (syenite). This injection has as a whole a less markedly abyssal character than the Famatina plutonic phase and belongs probably to a somewhat higher crustal horizon, than the last mentioned. It is evident that the white granite-syenite intrusion occurred in prepermian („pre-Gondwana“) time, because of the fact,

that the lower permian tillites rest directly over this twice granitized basement.

As was already stated in short, the white granite-syenite intrusions are met with principally in the western parts of the Umango area, outcropping as broader zones in the Sierra de Umango ridge and the Cerro Potrero Viejo. The whole intervening space between the former ridge and the Cerro Cacho is also rich of such dikes. In the last mentioned mountain there are similar dikes too, but a red granite, however, dominates. Only in one part the intrusion of white granite has an abyssal character, viz. in the northern end of the Sierra de Umango ridge. Generally the granite bands are folded together with the limestone banks without crushing, and this circumstance makes it evident, that the intrusion was *contemporaneous* with the tangential pressure.

The folding and the banding are also phenomena characterizing the appearance of the white granite-syenite. To the east, in the region of the Famatina batholith there are no signs of lateral stress, and a *younger granite seems to be lacking there too.* Bodenbender mentions no occurrence of this intrusive from there, and as to myself, I have never discovered any dikes of this rock inside the batholith.

Nothing further are known regarding the occurrences of younger (post-Famatina) granites in the pampean sierras-area, because the study of the chronology of the old intrusions in this area is still a task never touched upon. According to a verbal communication by Rassmuss, he has seen traces of a younger intrusion in the Sierra de Velazco, a white granite crossing the red one, the latter corresponding to the Famatina granite.

a) MANNER OF INTRUSION OF YOUNGER GRANITES AND SYENITES.

As already stated, the younger intrusives show a less conspicuous abyssal character than the Famatina red granite, and they depend to a considerable degree in their manner of intrusion on the struc-

tural planes of the schist mass. Crosscutting dikes are occassionally seen, but more irregular bodies with sinuous contacts and numerous apophyses are not met with. Brecciation, melting and assimilation are also odd phenomena, except a certain class of banding, where a lateral assimilation on a very reduced scale has succeeded. The whole appearance of the intrusion depended apparently upon a lateral controlling pressure, causing the mentioned *parallel* injections along the planes of weakness. The areal extension of the resulting *banded rocks* is a very considerable one. Although they are of the same origin as many common parallel arterites in archaean terranes, the banding in the Umango area shows a somewhat different character, due to an already mentioned lateral assimilation along the granite veins. The lateral assimilation is common especially where the granite intrudes amphibolite schists, from which results a product of intermediary composition. This last *is also banded,* evidently a result of parallel movements under stress conditions. Also at the borders of other schists such a banding was produced.

The banding phenomenon has been studied already long time ago in different archaean terranes. The following two classes may be distinguished: 1) Banding produced by flowing in a primary magma with the formation of *„Schlieren“* or streaks of different composition. The well known banded gabbro of Skye, Scotland, described by Geikie and Teall[1] belongs to this type. 2) Banding produced by the injection of magma along the structural planes of a schist mass. This type is the more important one and is *of regional extension,* as is shown by investigations in many parts of the world.[2]

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[1] A. Geikie and J. J. H. Teall: Banded Igneous Rocks of Skye. Quarterly Journal of the Geological Society of London. Vol. L. 1894.

[2] J. J. Sederholm: Om granit och gneis. Bull. Comm. Géol. de Finlande. N:o 23. Helsingfors 1907.

P. J. Holmquist: Zur Petrographie und Geologie von Ornö Hufvud. Bull. Geol. Inst. of Upsala. Vol. X. 1910.

Adams and Barlow: Geol. of the Haliburton and Bancroft Areas, pro-

The banded rocks in the Sierra de Umango area may be regarded rather as a combination of the two classes characterized above: flow-banding and parallel injection. In the cases, when the lateral assimilation has progressed very far, i. e., when the invaded rock to a greater extent has been dissolved in the granite, one observes the development of a rock banded by flow too.

I have studied the case of lateral assimilation of amphibolite-schists by granite. The whole injection-banding and assimilation is well exposed in the Quebrada Agua de los Caballos, on the eastern slope of the Cerro Potrero Viejo. Here may be observed, that the amphibolite becomes by and by more acid by lateral mingling, not continuously, however, but in the form of bands of decreasing basicity. Simultaneously *the amphibole changes into biotite* (Plate IV, fig. 1). The last assimilation product *is a biotite gneiss.*

About the transformation of amphibole to biotite Van Hise[1] says: „The change from hornblende to biotite is a much deeper seated alteration (compared with the alteration to chlorite), particularly in connection with profound mechanical action“. Regarding the change caused by granite assimilation (addition of salic material) the same author states: „the feldspar .... frequently furnishes the potassia, part of the aluminia and silica, while the amphiboles frequently furnish a part of the magnesia, aluminia and silica“ *to form the biotite.* The conditions in the Sierra de Umango may offer a *combination* of the two possibilities, above cited.

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vince of Ontario, Canada. Dept. of Mines. Geol. Survey. Mem. *6*. Ottawa, 1910. P. 73.

R. A. Daly: Geol. Reconnaissance between Golden and Kamloops, B. C., along the Canadian Pacific Railway. Ibidem, N:o *68*. Ottawa 1915. Pages 34 and foll.

C. N. Fenner: The mode of formation of certain gneisses in the highlands of New Jersey. Journal of Geol. Vol. XXII. Chicago 1914. A. o.

[1] C. R. Van Hise: A Treatise on Metamorphism. Page 290.

b) PETROGRAPHICAL CHARACTERISTICS OF THE YOUNGER INTRUSIVES.

The greater bodies of this class of intrusive rocks in the Sierra de Umango area seem to consist of a white-gray *syenite,* quite large grained and very poor in mafic minerals. Only where there are inclusions of some basic, strange rocks, an assimilation product of a more basic character may be observed. Where these intrusives appear in form of dikes, they are mostly granites and pegmatites, all of acid character. Where crosscutting dikes occur, they consist of a finegrained aplite.

The easternmost occurrences of the white intrusives are met with in the crystalline hills of Las Ramaditas, where crosscutting dikes of the aplite and also of white pegmatite are visible on quite a large scale. The pegmatites are rich in quartz, and have been but slightly crushed by later movements, thus contrasting with the occurrences of the same rock further to the west (except where the rock lies between limestone banks). The aplitic dikes are of quite fine even grain and show microscopically a somewhat crushed structure, probably depending upon a protoclasis, owing to the circumstance, that the dikes are cutting straight through the schist mass, without flexures or ruptures.

Further to the west, in the abrupt eastern slope of the Cerro Villa Union, opposite the hills of Las Ramaditas, there occurs a boss of a white syenite. I had no opportunity to study this intrusive body and its contact lines. I only collected some specimens from a river bed leading down the slope from the heart of this massive. The rock consists, according to these boulders (huge masses), of an almost monomineralic kind of evengrained intrusive, an albite-oligoclase mass. The feldspars are generally very altered by sericitization. Muscovite is also a constituent, but not abundant. Quartz was not detected, neither in handspecimen nor in microscopical slides. The structure seems to be completely free from crushing phenomena.

The structures of the white intrusives, occurring more to the west (in the high ridge of the Sierra de Umango etc.), will be treated of later on, as they all belong to secondary structures of dynamical origin, caused by the tertiary movements.

D) KATACLASTIC STRUCTURES OF THE BASEMENT ROCKS, PRODUCED PRINCIPALLY BY LATER (TERTIARY) OROGENETIC MOVEMENTS.

As will be shown [1] later on, the whole Sierra de Umango area was affected during tertiary times by orogenetic movements. In an earlier phase these manifested themselves by a tangential pressure from the west, causing am. o. the folding-tectonic in „the intermontane zone". It will also be shown, that the Umango area forms a part of „Foreland" or „*avant pays*" to the andean chain.

These eastward pushing tangential movements produced not only different disturbances in the continental sandstone cover. The crystalline basement was also strongly affected and a *regional kataclasis* developed in it. The following petrographical description may be a study of the crushing phenomena of the rock minerals, referring to the well known researches of Leith. [2]

It might be supposed, that some of the below described secondary structures may originate from an earlier diastrophic period than the tertiary, for instance, from the same phase, when the white granite was intruded. It seems, however, probable, that the kataclasis developed during this period, *was brought to recrystallisation* by the subsequent intrusion of the white granite.

The tertiary tangential pressure released along NNE running overthrust planes and broke up the Sierra de Umango crystalline base-

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[1] Tertiary tectonics, in Part II.

[2] C. K. Leith, Rock cleavage. U. S. Geol. Survey. Bulletin 239. Washington 1905.

ment into a number of great fault blocks. The downpressed sandstone-remnants lie between the blocks in the throws. The crushing of the basement rocks apparently went on *through the whole complex.* The intensity varies, however, considerably. The most complete granulation occurred along the overthrust planes, in whose immediate vicinity a mylonitic breccia was developed. The crushing and tearing was intense also where schistose rocks dominate, while in the granite stocks conspicuous signs of pressure have been observed more locally. Generally, *the degree of deformation* may be said to *decrease towards the east.* In the batholith of the Nevado the granulation of the granite structures seems to have been of a more local nature, while the bulk of the eruptives shows quite a well preserved consolidation habit.

a) THE CRUSHED, GRANULATED GRANITES.

In the foregoing pages the granites of the Sierra de Umango area are petrographically characterized only to a small extent, because *primary granitic structures seldom occur.* The greater part of the granite outcrops shows more or less conspicuous signs of dynamical deformation.

In the following pages may be examined the secondary structures of the granites in the order as they outcrop, going from east to west.

Above have been treated of the Famatina batholith types. They show generally quite a primary habit. Passing the valley to the Sierra de Umango side, in the next zone (schists with crossing apophyses) conspicuous crushing features are lacking (graphic pegmatites!) But some miles farther west, in the eastern slope of the Cerro Villa Union, there are already strong pressure phenomena. The concordant granite veins in the schists have been torn off into lenses and the structure is completely granulated. It is here seen a typically developed banded zone. As a good example of a crushed concordant pegmatite vein an occurrence from the western foot of the mentioned mountain (Carrizal) may be described. Already in

handspecimen the rock shows a marked dynamic flow structure, but microscopically it is the most typical of this kind: the parallel is produced by the alternate of strokes of quartz grains and feldspar + muscovite grains, the whole showing a great similarity of the parallel, crushed granite structures described by Leith.[1] The strokes have been formed by the breaking off of larger grains. The quartz bands have afterwards undergone a recrystallisation in some degree (see microphotograph, Plate V, fig. 1). The granite described lies in a mica schist complex, strongly pressed too. – In the whole mass of the Cerro Villa Union the pressure phenomena are quite of the same intensity.

On the crest of the Sierra de Umango ridge there is, as has been mentioned, a zone of red, aplitic granite, concordantly penetrating the schists. In handspecimen the granite has a marked parallel structure („gneiss-granite") apparently of dynamical character. Microscopically the rock shows a middle stage of granulation with many variations in size of the grains. The quartz has afterwards recrystallized to some extent, as seen from the sinuous contours of some larger, unbroken grains. The feldspar is partly albite-twinned and very altered by chemical decomposition, partly a badly developed microcline. Mafic minerals are lacking with exception of small spots of biotite.

At the western foot of the same mountain ridge, near to the Arroyo Gaucho, following his border, there is outcropping quite a large zone of a red, aplitic granite, bordered upward by the lustering mica-schist-zone. Because the granite zone runs almost conformably with a tertiary dislocation line (the Pirca dislocation), this rock has undergone an intense crushing. The kataclasis seems to increase downward in the mountain slope, being most intense along the very fault line (at the foot). The extremely crushed specimen shows a habit of an „aplitic schist" (Plate V, fig. 2). A transversal

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[1] Rock cleavage. U. S. Geol. Survey. Bull. 239. 1905.

microscopical slide of this type demonstrates a very fine granulation of the quartz and feldspar components. The secondary grains are all isometric in shape and the parallel structure is less conspicuous than in handspecimens. Flat lenses of a secondary, opaque substance can be seen, probably the last remnant of some mafic minerals (amphibole?).

In the Cerro Cacho complex all the granitic stocks of longitudinal shape and the concordant dikes have been affected by the tertiary and partly also by some older movements. The most intense crushing appears near to the western border of the complex, where the bordering fault-line runs (to the west from Quebrada Cacho and Quebrada Agua de la Piedra). On the eastern slope of the mountain, where the seleniure mining area is situated,[1] there is a large, longitudinal stock of aplitic granite, penetrating amphibolite schists and limestone banks. The granite has been transformed into gneiss by pression phenomena. That the pression here really belongs to an older phase is seen from the circumstance, that the granite has been folded simultaneously with the surrounding schists, *and is penetrated by a dike of white pegmatite.* A handspecimen of the red granite shows a distinct parallel structure, but not a schistose one. The mineralogical composition of the rock seems to be that of an eutectical mixture. The graphic texture has indeed been torn off. But in spite of the strong pressure the quartz and feldspar components have not been mingled together to a higher degree, a fact, proved also microscopically. The microscopical examination shows, that the resulted grain of the rock is a „double“ one, that is, every individual has been broken off into smaller fragments holding to some extent their original position. This is the case especially with the feldspar grains, while the quartz mostly forms a cementering or filling mass between the feldspar aggregates. This quartz mass has a dynamical flow arrangement, but generally with an oblique di-

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[1] See the concluding chapter, Part II.

rection compared with the general flow direction of the rock. The feldspar grains are very altered, and belong probably all to the potash feldspar group. In an extreme case of pressure the aplite granite, or more exactly the graphic granite, has been torn off to a kind of a fine banded rock, like the banded hälleflinta, consisting of alternating layers of quartz and feldspar. The structural direction is moreover marked by the appearance of parallel biotite flags.

b) DEFORMATIONS IN THE SEDIMENTARY SCHISTS.

Among the sedimentary schists of the Sierra de Umango basement the mica schists are the most affected by the tectonical movements. The general habit of these rocks indicates with complete evidence, that they must have undergone a strong kataclastic metamorphism. The development of quartz lenses, folds and faults is found everywhere, and also microscopically the helicitic structure. Especially the abundant manifestations of secondary quartz-lenses and layers in all parts of the area are a characteristical feature of the powerful dynamical influence in these kinds of rocks.

A specimen of the lustering mica schist from the western side of the high ridge of the Sierra de Umango demonstrates microscopically a strong folding of the mica planes, conducing in extreme cases to the „Slip cleavage" (Leith). The rock mass between the mica planes is composed of small quartz grains.

The forming of quartz lenses between the schist planes conduces to a *lenticular structure,* a characteristical phenomenon in the zone of katamorphism. This phenomenon was evidently a tertiary one and not contemporaneous with the granite injections, as the lenses never show connection with acid granitic apophyses. Sometimes these secondary quartz lenses are thinned out so as to form regular layers alternating with the mica planes, thus producing a type similar to the „Lagenglimmerschiefer" of Rosenbusch.

The circumstance, that the mica schist-zones are especially affected by the gliding and crushing phenomena, may be explained by assu-

ming the named zones as ways of weakness, the mica planes having played the part of gliding surfaces.

On a very much smaller scale we find the pression phenomena developed in the quartzitic schists, where generally every kind of crushing is lacking. Also the grains of quartz are individually well conserved (after the last recrystallization) and no signs of „undulating extinction“ can be detected. The slight mechanical deformation can be seen already in handspecimen, whose surface shows a distinct glassy apparition (in the transverse cuts). This remarkable consistense of the rock can be explained in general by a greater hardness and coherence characterizing this kind of crystalline schists.

The crystalline limestone, occurring, as mentioned, principally as folded banks in the western part of the Umango area, was intruded by white granite and pegmatite simultaneous with the folding process. By this process the rock became completely recrystallized, and afterward — during the tertiary time — no crushing deformations have occurred, except in some isolated localities, where faults cut across the banks.

c) KATACLASIS IN SOME „DARK SCHISTS“.

A group of dark schistose rocks, characterized above petrographically, affords a very excellent example of the tertiary dynamic metamorphism. They are sometimes of a doubtful origin. Compared with the ordinary amphibolites they are much more granulated, a fact preventing essentially the examination of the real nature of the rocks.

Microscopically the dark schists often develop a porphyroclastic structure (Plate VI, fig. 1). The larger grains are composed of plagioclase and amphibole. When quartz occurs, it has been so intensely granulated, that it forms a kind of groundmass. This fine detritic mass has a flow arrangement, bending around the larger grains and containing also abundant minute amphibole and biotite fragments of elongated forms, especially marking the flowage directions. An interesting example is illustrated on plate VI, fig. 2, where

biotite plays the part of „phenocrysts“ and greater lenses, while the fine granulated mesostasis is composed of quartz and sericite.[1]

E) GENERALITIES ON THE GEOLOGICAL POSITION OF THE SIERRA DE UMANGO AREA.

As a consequence of the scarceness of our knowledge of the geology of the vast area composed by crystalline, partly sedimentary and partly igneous, rocks of the central part of the Argentine Republic, appearing in the so called „*Sierras pampeanas*“, reaching to the very border of the Andes, it will be a difficult task by a limited surveying in this area (the Sierra de Umango) to explain any broader tectonical and structural relations. Working in the Sierra de Umango area the writer did not get any occasion to make excursions into the surrounding countries so as to obtain more general views. The existing litterature and the maps of the neighbouring districts, lately prepared, have, however, facilitated an attempt to a somewhat broader synopsis, although the results may be in many respects only hypothetical ones.

The general orientation of the metamorphic schists in the „*Sierras pampeanas*“ has been fixed as running nearly N—S over wide areas. Also in regions near to the Andes this crystalline basement shows a similar behaviour. The schists of the Sierra de Famatina, the Sierra de Umango and also of the Sierra Pié de Palo farther south are roughly trended into this general orientation.

Granitic bosses and batholiths of various extension are intruded into the gneiss and schist complexes at various times and have caused a regional metamorphic, and in many cases ultrametamorphic change of the preexistant rocks. Similar kind of abyssal metamorphism has overgone, as has been shown above, also the Famatina—Umango schists, principally by intrusion of the Famatina batholith.

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[1] See also Plate VII, figg. 1 and 2.

The abyssal character of the rocks dominates westward to the very border of the Andes, where suddenly clastic rocks appear. The limit between the crystalline area and the clastic series of this part of the Andes may thence be represented by a great fault line.

A similar contrast exists between the lithological composition of the Sierra Pié de Palo and the near lying parts of the Precordillera.

The rocks forming the area of the pampean underground and the „*Sierras pampeanas*" and lying under the cover of the continental formations, are quite different in their lithology but as mentioned of a strong metamorphic habit. The age of the various members is evidently also different. A recapitulation of earlier and later views on this matter may be justified.

The first opinion, according to Stelzner (1876) was, that all the crystalline rocks outcropping in the „*Sierras pampeanas*" belong to the precambrian. This author divides the whole complex into two principal lithological groups: 1) *an inferior* gneissic, intensely granite intruded and of distinct abyssal character, and 2) *a superior* schistose, of evidently sedimentary origin as a whole and only to a limited extent intruded with granite. This Stelzners opinion must be considered quite a correct one, regarding the general lithology and the relative position of the named complexes. But another question arises, when regarding the age of all these rocks.

According to Stelzners descriptions and sections from the Sierra de Famatina it is quite evident, that he considered all the quartzitic and argillitic schists of this range as of precambrian age, but that the relation of these rocks to the fossiliferous siluric strata of Potrero de los Angulos remained an undissolved problem. Concerning the discovery of silurian fossils Stelzner says, that he prefers not enter into discussion about the fact, that silurian rocks were found to the *east* of the Sierra de Famatina ridge, i. e. far away from the silurian outcrops in the axis of the „Anticordillera" (today named the „Precordillera"). In order to dissolve this problem Stelzner had to few observations.

Later on Bodenbender has more closely investigated the same ridge and also many others of the „*Sierras pampeanas*", and from there concluded, that in the Sierra de Famatina and somewhere else in the crystalline basement *lower paleozoic sediments do occur.* They are partly penetrated with granite, as in the case with the mentioned silurian strata in the Famatina mountain. On the eastern side of the latter Bodenbender discovered cambrian slates, containing *Dictyonema* and *Staurograptus,* and limestone banks with *Obolus* and *Agnostus.* In a report (1916) about the Nevado de Famatina Bodenbenders opinion is: The intrusive granitic body of the named mountain, now vastly exposed on the surface, contains great inclusions of various schists, probably all of cambrosilurian age (see the little sketch map, page 30). In some small parts of better preservation they contain fossils, but are usually metamorphosed to a quite high degree by the granitic body and its innumerable apophyses. Also mingled rocks (migmatites) occur in lower horizons. The continental or „Paganzo" strata (Gondwana and red beds) in the Famatina mountain are to be found only to a small extent, and Bodenbender says: „*la propagación reducída del permiano-carboniano .... a causa de su dislocación y denudación nos priva de poder observar eventuales intrusiónes*". This statement shows, that Bodenbender had no firm opinion regarding the relation between the granitic intrusion and the covering „Paganzo" strata. Further the author supposes, however, that the intrusion probably occurred in permian or already in carboniferous time, while the „Paganzo" seems to lie partly „conformably" with the cambrosilurian schists. A such „conformity" was observed by Stelzner too from Potrero de los Angulos.

During a crossing of the Nevado de Famatina (Paso La Pampa— El Tocino) on the backward journey from the Sierra de Umango district the writer had some occasions to study the geological relations. The many tectonically sunken remnants of red beds lie with basal detritic layers on the Famatina granitic rocks or on the por-

phyry complex, composing the higher parts of the ridges. The porphyry series stands, as seems, in magmatic relation to the granite. At the western foot of the mountain lower „Paganzo“ (pale coloured sandstones and conglomerates) lie on a granite ground, while on the eastern side similar beds are downfaulted between the old porphyries and vertically tilted mica schists, the latter forming mountains and ridges to the east from the Nevado. Nearer to Chilecito the granite again appears.

It seems quite probable, that in time between the consolidation of the Famatina batholith and accompanying porphyries, and the sedimentation of the continental strata there took place a great break in the succession of the geological records, i. e. a hiatus of erosion. The basal plane of the „Paganzo“ series represents without doubt in general a deep geological horizon (cut) indicated by the predominance in the basement of coarse grained granites, molten and resorbed inclusions of rocks and also by the steep position of the mica schists. The observed „concordance“ mentioned by Stelzner and Bodenbender as existing between these schists and the „Paganzo“ strata may probably be explained as tectonical juxtaposition, a common phenomenon also in the region of the Sierra de Umango. I am consequently inclined to accept the old opinion of Stelzner, regarding the Famatina granite being of postsilurian age.

When regarding the other „*Sierras pampeanas*“ one may find, that there occur in many regions zones of sedimentary schists, limestones and conglomerates, apparently representing younger members, downfolded in the old precambrian gneisses and intruded schists. In the Sierra de Córdoba[1] for instance, we find amidst an old gneissic terrane a smaller remnant of coarse clastic layers, pressed conformably to the former and also many outcrops of folded limestone zones of evidently silurian habit. Also in the Sierra del Gigante, in the Sierra de los Llanos and in the Sierra Pié de Palo

[1] G. Bodenbender: La Sierra de Córdoba. Anales del Ministerio de Agricultura de la Nación. Sección Geología, Tomo I. N:o 2. Buenos Aires 1905.

there are many such younger zones of true sedimentary origin.[1] Keidel[2] and Rassmuss[3] have later on also expressed the opinion, that they may represent in some parts lower palaeozoic members, and that thence the hiatus under the covering permo-carboniferous strata may be less important than corresponding to the old opinion of Stelzner.

It is, of course, in many cases very difficult to determine, if the downfolded younger members really are of lower palaeozoic age. From the province of Catamarca Rassmuss has reported a complex of probable algonkian, separated from an older archaean body by a marked unconformity (basal conglomerate). The younger complex consists of quartzites and mica schists. In the sierras to the west from Tucumán and further to the north there is a broad zone of chloritic and other schists, extending in the general N—S direction. The schists are of precambrian age, as shown by Keidel[4] from his investigations farther to the north, in the province of Salta, where fossiliferous upper cambrian with a marked unconformity lies over the strongly folded (and also mylonitized) complex of the northern continuation of the same schists.

Apart from these sedimentary zones the bulk of the complex of the „*Sierras pampeanas*“ seems to consist of gneissic and mingled rocks together with extensive granitic bodies. The last named are partly of palaeozoic age, as shown by the fact, that they penetrate the sedimentary rock members (limestones a. o.), whose lower palaeozoic age is beyound doubt. Great gneissic complexes are met with in the Sierra de Córdoba, Sierra de San Luis and also in the Sierra de Velazco.

The coincidence of the orientation of all the schistose and gneissic rocks of the „*Sierras pampeanas*“ (incl. the Famatina—Umango

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1 G. Bodenbender (1911). See the geological map.
2 H. Keidel (1914). Page 674.
3 Juan Rassmuss (1916).
4 H. Keidel (1914). Page 674.

area) indicates, that the folding power at different times of pre-cambrian and older palaeozoic periods was working almost in the same or in opposite directions. That fact increases the difficulty of recognizing structures of different ages in this region.

As a matter of fact, resulting from the foregoing treatment, *the Famatina and the Umango schist complexes must be considered as older palaeozoic members, by downfolding incorporated in the old basement and strongly metamorphosed by subsequent granitic intrusion.* The granitization belongs to a period, antedated to the time of the permian orogenetic phase. The lower Gondwana rests, as we have seen, with a great unconformity on the granite intruded schists. Thence, the Umango structure cannot, as Penck believes, be any continuation of the Precordilleran structure, but is an older one. The juxtaposition of these two structures is caused by later movements (the permian [Precordilleran] and also the tertiary [Cordilleran]). In the Umango area the deep geological level of the pampean underground and the „*Sierras pampeanas*" is thence brought side by side with the more supercrustal masses of the Precordilleran palaeozoic formations.

Because the position of the Umango area in the immediate front of the permian and tertiary andean folding zones, the area in question has played the part of a „foreland" during at least two diastrophic phases and has consequently also undergone tectonical influences, differing from these of the „*Sierras pampeanas*" in general.

This circumstance makes the Umango area to an interesting field for studying mutual petrographical and tectonical relations, as the foregoing chapters may have illustrated.

PART II.

„POSTGRANITIC“ CONTINENTAL DETRITIC FORMATIONS. VOLGANIC ROCKS. TERTIARY TECTONICS. GEOMORPHOLOGY. MINERAL OCCURRENCES.

A) THE BASIS OF SEDIMENTATION OF THE CONTINENTAL STRATA.

The sub-Gondwana denudation.

The great variety of crystalline rocks composing the „Umango structure“ plays, as mentioned, the part of a basement supporting a mighty series of detritic, continental strata. Evidently a very great hiatus corresponds to the unconformity between these two lithological elements. It may therefore be assumed, that the denudation which produced this unconformity, must have been considerable as shown from the great areal exposition of the Famatina batholith of today, with all its melted and mingled rocks originated by the abyssal injection phenomena.

The still visible remnants of the basis of sedimentation of the continental strata in the Umango area and surroundings are preserved only where the overlying strata have been recently removed by erosion, or where steep, crosscutting profiles are exposed. In all other parts the basal plane has been completely destroyed in consequence of later tectonical disturbances in the region, or it is concealed by still overlying strata. The following exposures may be mentioned: 1) Arroyo Blanquito, on the western side of the Cerro Villa Union to the south. Here the plane is steeply dipping to the SE and overlaid with the lower Gondwana sediments. It appears also on the SE side of this mountain, in the Quebrada de los Lagares. Some leagues to the south in the high western profile of the Cerro Bola, described by Bodenbender (1911), the plane is not visible, because hidden beneath piedmont accumulations. 2) Cerro

Colorado and vicinity, on the eastern side of the Cerro Villa Union. Here the plane is uplifted partly to a relatively high position and has a SE dip. In the through-going Quebrada Banda Florida farther to the north the plane forms the bottom of the quebrada and is overlaid with red sandstone. 3) Cerro Potrero Viejo, southern part. Here the plane is quite broken, but seems to dip in a southerly direction. Lower Gondwana lies over it with a thin basal conglomeratic layer. 4) Sierra de Sañogasta, southern part of the Nevado de Famatina. The plane rises to great heights from southeast in the direction of the summit of the Nevado, appearing as an even crest line. It is, hovewer, somewhat doubtful, if this plane can be regarded as an equivalent to the former, because the age of the overlying red sandstone still conserved in some parts of the crest is uncertain.

B) THE CONTINENTAL SERIES.

Gondwana [Paganzo (La Rioja) strata] — upper mesozoic and lower tertiary beds.

Detritic sediments in perfect conformity.

According to geological maps[1] of the central western Argentina the areal distribution of the continental sediments, lying over the pampean — partly sunken and partly uplifted — crystalline basement, is varying in different parts of the region. While the outcrops of these clastic rocks in the more eastern parts as in the Sierra de Córdoba are insignificant, their extension increases gradually, when approaching the border of the Cordillera. The tectonical appearance of these series in the region of the „*Sierras pampeanas*" is in general such: Along the border of the horst-blocks (the *Sierras*) they form an outward dipping fringe, an erosion remnant of

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[1] Ludw. Brackebusch: Mapa geológico del interior de la República Argentina. Scale 1:1,000,000. Gotha 1891.

G. Bodenbender (1911).

varying height of an once covering mantle, uplifted by the horst-movement. These fringes are only the visible edges of the vast sunken parts of the same formations, occupying the space between the *Sierras* and today completely covered with the more recent pampa accumulations. Nearer to the Andes the outcrops of the mantle are growing larger, because the tectonical throws are getting narrower and the pampean accumulations are decreasing in thickness in the same direction. Here the mantle-outcrops also climb to greater heights over the valley floors. Especially in the provinces of La Rioja and Catamarca these continental series are developed to great extent in the geological structure. Their most typical representatives one will find in the former province incl. the Sierra de Umango area, and therefore they have been named the *La Rioja strata*. They correspond to the „Paganzo" of Bodenbender.[1]

Farther to the south in the Precordilleran zone the extension of the continental strata, according to the geological map by Stappenbeck (1910) comprising the area from Mendoza to Jachal, is less conspicuous, but still quite considerable.

The principal extension of the „Paganzo" or La Rioja strata was studied and fixed on the map already 40 years ago by Ludw. Brackebusch.[2] The series in question was called by him *„terrenos reticos"*, according to the earlier determinations by Geinitz (1876). They include also many volcanic sheets. The „rhaetic" age, however, was in many cases considered by Brackebusch as doubtful, as may be seen from the many notes of interrogation on the map. Later on Bodenbender (1896) divided the series more closely into „carboniferous", „permian", „triassic" and „rhaetic" formations. This division was partly based on discoveries of plant remains in the strata. In a later paper by the same author (1911) one find the following scheme: the carboniferous, permian

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[1] (1904). See later on.

[2] Ludw. Brackebusch, l. c. (1891).

and triassic beds are united by him under the denomination „Paganzo strata". In this group, lying generally in concordance, except the Precordilleran zone, and being wholly of continental character, Bodenbender distinguished between three subdivisions of quite different habit: „*Piso*" I, II and III. The conformable hanging strata he considered as rhaetic, jurassic and cretaceous, the last named being in the subandean regions of coarse detritic, in extra-andean (pampean) areas of calcareous habit.

Regarding the Sierra de Umango area, a similar stratigraphical division will hardly be applicable, because of the many breaks in the succession of the strata caused by tectonical tearings and also because of the extreme scarceness of fossils. Stappenbeck already met with the same difficulties in the Precordillera (between Mendoza and Jachal). In similar circumstances worked also more recently W. Penck in the province of Catamarca, or nearer said in the region of the valley of Fiambalá (1920).

In the following pages there will be communicated a more detailed description of all important occurrences of the continental strata, and then the writer makes an attempt to divide the whole series on the basis of lithological, stratigraphical and tectonical relations.

a) DESCRIPTION OF LOCALITIES.

The Cerro Guandacol (The southern part of the Cerro Villa Union).

The most complete and most representative profile through the lower part of the continental series is exposed here, especially on the abrupt western side of the mountain, some miles to the east of the village of Guandacol situated on the river La Troya.[1] The westfacing slope is due to a great fault, running at long distance in a north-southerly direction along the eastern border of the valley of Rio La Troya (Rio Bermejo). The profile of the Cerro Guandacol was described at various times by Bodenben-

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[1] See the profile fig. 7.

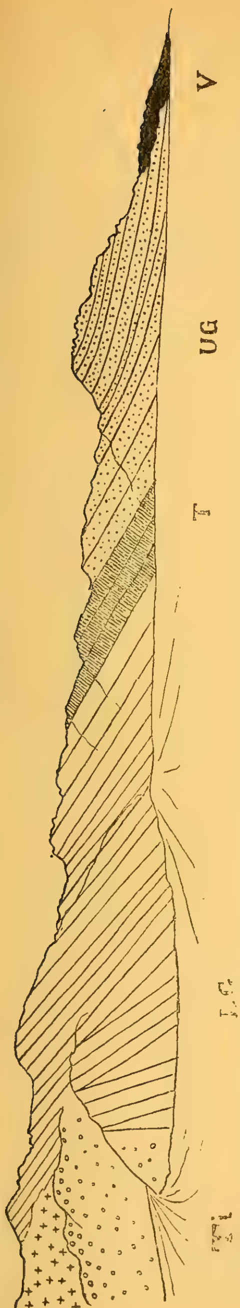

Fig. 7. A natural profile along the western side of the Cerro Guandacol (southern end of the Cerro Villa Union), seen from the Guandacol valley, ome miles distant. To the extreme left (crosses) the crystalline basement. Ti: tillite. LG: lower Gondwana sandstones and shales. T: tuff layer. UG: upper Gondwana red sandstones and coarse grained arcoses. V: volcanic agglomerates.

der and also figured in a somewhat schematized manner (1897). Over the crystalline basement, which forms, as mentioned, a SE-dipping basal plane, there lies with the same dip (45°—30°) a mighty series of continental strata of different colours. This series continues along the southeastern side of the mountain (see later on), forming here a steep-dipping mantle. The whole series sinks rapidly beneath quaternary accumulations in the south, but farther in this direction it rises again in the great anticlinal upward bend of the Cerro Bola, as Bodenbender has already stated (1911).

The basement of the profile is composed of mica and amphibolite schists penetrated with red pegmatitic granite. The schist rocks have a slight northward dip contrasting with the steep inclination of the schists in all other parts of the Cerro Villa Union. This circumstance may be explained as a simple block tilting of the basement part lying under the sediment cover. The degree of the tilting is already evident from the dip of the strata.

Regarding the lithology of the strata, at the base there is a conglomeratic layer, composed of quite heavy boulders of angular forms from the same rocks, that occur in the basement. The

greenish matrix is here quite scarce. This conglomerate is well visible in a locality called Arroyo Blanquito. The dip of the conglomeratic layer is here very steep, nearly vertical, but this fact is due to a local faulting of a later age than the general tilting. Upward the conglomerate changes its lithological habit thus that the size of the boulders decreases, while the relative quantity of the matrix is growing mightier. The forms of the boulders change upwards to more rounded ones. Finally the matrix is almost dominant, and a „graywacke“ results without any conspicuous bedding. The rock contains small irregularly scattered boulders, and is quite well cemented: a polyhedrical jointing may be observed.

There is no doubt about the genesis of the „graywacke“ rock, observed already by Bodenbender in another locality (see later on). The rock reminds one of the permian glacial boulder beds in the Precordilleran zone farther to the south, discovered by Keidel (1914). The lithological resemblance of the tillite described by Keidel in the classical profile at Jachal (I had also an opportunity of seeing the rock) is very great. The coarse conglomerate at the base of the „graywacke“ in Arroyo Blanquito is clearly not waterworn. Although striae are not yet discovered, neither on the boulders nor on the basal plane, the conglomerate may be considered a moraine boulder bed.

Upward from the „graywacke“ in the profile (to the south) there follows a sandstone of grayish colour, nearer the base alternating with a clayish slate. These rocks are overlaid with a similar slate as below and of considerable thickness. The slate is covered with a grayish sandstone.

I am inclined to regard the pale-coloured sandstones and slates near to the roof of the graywacke as a *pelodite*[1] or glacifluvial outwash products from a time subsequent to the deposition of the

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[1] J. E. Woodworth: Geological Expedition to Brazil and Chile 1908—1909. Bull. of the Museum of Comp. Zool. Harvard Univ. Vol. LVI. N:o 1. Cambridge, Mass. 1912. Page 78.

morainic matters. Somewhere in the sandstones and slates (probably more upward) Bodenbender has (1911) discovered badly preserved remains of plants, among which has been determined:

Neuropteridium, sp.; *Equisetites (?).*

This series of pale-coloured sediments is capped by an almost 100 feet thick sheet of a peculiar chocolate-coloured, dense and unstratified rock, having the odour of humid clay. Microscopically the rock has been proved to be a pelitic tuff. Over this bed follows in perfect conformity a mighty series of red and brown sandstones.

There is no doubt about the pale-coloured sediments below the tuff layer as corresponding to the *lower Gondwana,* i. e. to the Talchir-Karharbari-horizons.

A series of red and reddish brown sandstones of the coarse arcose types succeeds over the brown tuff sheet with perfect conformity, partly almost psephitically developed and consisting mostly of angular grains of red feldspar and milkwhite quartz. The upper strata are all darker coloured and capped with volcanic agglomerate and ash layers.

To the south from the Cerro Villa Union rises, as has been mentioned, the great upbend of the Cerro Bola, showing the same sequence of strata, but without the crystalline basement exposed. The profile here, forming an abrupt wall toward the Guandacol valley, was studied by Bodenbender (1897 and 1911). In these lower Gondwana layers he discovered in a carbonaceous layer the following plant remains:

Neuropteridium validum, Feistm.; *Noeggerathiopsis,* sp.

To the east the Gondwana layers are concordantly overlaid with rhaetic and younger formations, dipping towards the Pagancillo lowland [Bodenbender (1911)].

Turning back to the Cerro Villa Union it may be observed, that the strata, described in the profile of the Cerro Guandacol, run with

almost the same inclination and direction along the whole southeastern side of the Cerro Villa Union.

Looking from the Pagancillo lowland toward the mountain, the steeply dipping cover appears as a gigantic „steel sheet“ capping the crystalline mass. A study of the succession of the strata in this cover appearing in profiles in the many crosscutting quebradas reveals, that several members from the Guandacol profile are lacking.

A good cut through the cover can be studied in the Quebrada de Los Lagares (fig. 8) situated to the northwest of the little ranch Aguada de los Burros (this locality lies on the path from Villa Union to Guandacol). Over the crystalline basement, here composed of a mica schist, lies with a dip of almost 45° a pale yellowish sandstone, carrying a clayish slate in regular alternation. The basal conglomerate and the „graywacke“ lacks here. The yellowish sandstone is succeeded by a red one of the same dip. The yellowish sandstone incl. the slaty interstratifications attains surely the thickness of two hundred meters. The red beds above contain some concordant sills of melaphyre, partly of spilitic development. A longitudinal erosion valley separates the red layers from the immediate horst-flanc cover, the former standing out as long-crested foothills (visible on the map). The dark melaphyre sheets are discernible already at a long distance.

The thick, chocolate-brown tuff sheet from the Guandacol profile is not represented here. But the melaphyre corresponds surely to the same volcanic phase.

Further to the northeast one finds the same succession of strata as in the Quebrada de Los Lagares. In the vicinity of the mouth of the Quebrada Barreal (not named on the map), situated opposite the Cerro Punta Colorada, at the base there appears the same yellowish sandstone resting directly on the basement, here composed of granite and of intruded and banded schists. The slaty interstratifications seem to be lacking. Over the yellowish lower Gondwana sandstone lies then a red sandstone of the same ap-

pearance as that farther to the southwest. Regarding the tectonics may be mentioned, that the yellowish sandstone upward changes its dip forming a flat-lying cover over the crystalline bulk. It is the only part of the area, where the Gondwana have been observed in an almost horisontal position resting *upon* the basement's upland surface.

Northward off this locality the Gondwana layers rapidly dissappear due to faults.

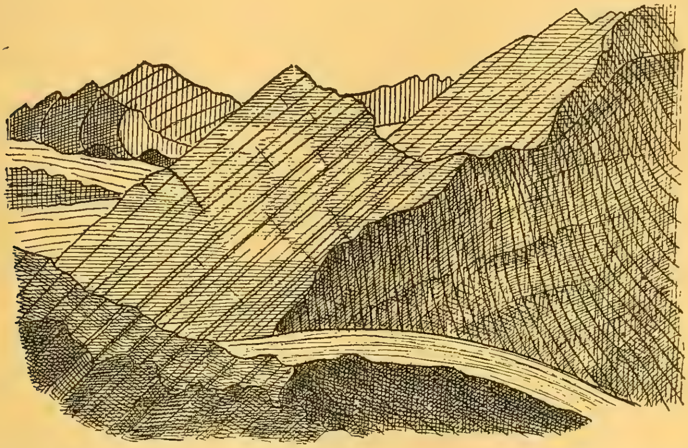

Fig. 8. A cut through the sediment mantle along the southeastern slope of the Cerro Villa Union in the Quebrada de los Lagares. Lower Gondwana sandstone and slate in regular alternation lying over the crystalline basement (mica schist). Looking south with the Cerro Bola in the distance.

The region of the Cerro Punta Colorada — Las Ramaditas.

A continuation of the southeastern flanc-cover to the northeast forms in some degree the group of foothills, situated between the steep eastern side of the Cerro Villa Union and the valley of Vinchina. Here the cover, however, has been broken into many small blocks and the outcrops of the strata show therefore a greater variety. Also the dips are more variable. This foothill-group consists of two essential parts, an exterior one, facing the eastern lowland, the Cerro Punta Colorada and its ramifications consisting of sandstones, and an interior one, Las Ramaditas, composed of

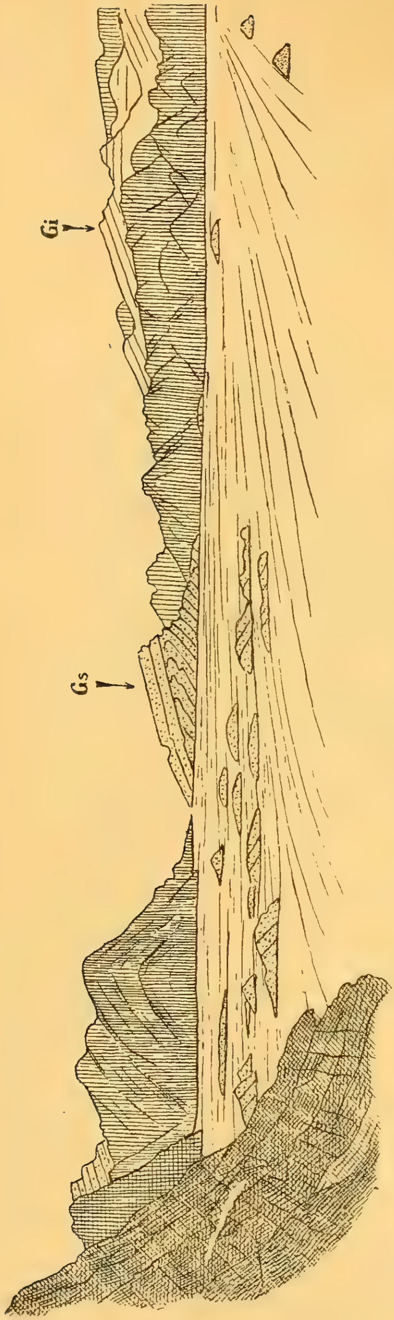

Fig. 9. Looking south over the gravel plain between the eastern side of the Cerro Villa Union and the hills of Las Ramaditas. The dark slopes consist of old crystalline rocks. The dotted parts (Gs) are red triassic beds, occupying the whole underground under the gravel sheet. The unsigned strata to the right (Gi) are of the lower Gondwana, principally pale yellowish sandstone.

rocks of the crystalline basement. Among the crystalline hills in the latter part there are many small remnants of sandstones too. The hills are separated from the Cerro Villa Union complex by a train of piedmont gravels, running north-south (fig. 9).

This broken ground may, as stated above, be regarded as a border tectonic to the great sunk area of the Vinchina valley—Pagancillo lowland. The strata in the Cerro Punta Colorada dip toward the lowland, except with many small irregularities. The northern part forms a kind of mantle above the core of the crystalline ground of Las Ramaditas.

The sediments of this area are well exposed in many profiles, especially to the south of Las Ramaditas. They were examined repeatedly by Bodenbender (1896, 1897, 1911), principally at the foot of the Cerro Punta Colorada.

The series here is more

complete than at the above described localities along the slope of the mountain. It shows, as shall be found, a remarkable similarity with the already described strata in the profile of the Cerro Guandacol.

The sandstone ridge shows but few through-going quebradas, among which the most remarkable is the Quebrada Banda Florida. Another is the Quebrada Colorada, more to the south. In the former gorge the sandstone ridge is cut across down to the crystalline basement. In the interior the same immediate contact is visible in many localities, for instance at the northern foot of the Cerro Punta Colorada.

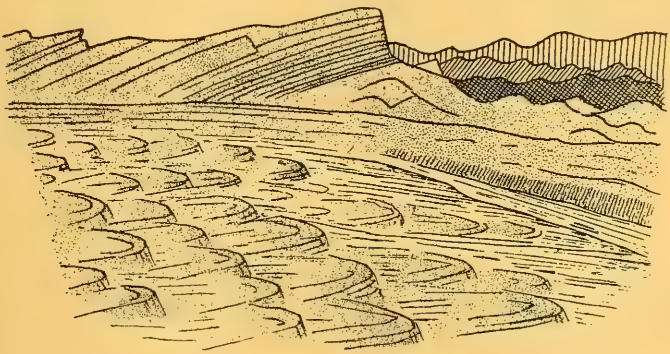

Fig. 10. The Cerro Punta Colorada from the north, showing the Gondwana strata dipping SE-ward from the crystalline basement (darker). In the foreground the subsequently dissected floodplain of Rio de los Noques.

The stratigraphy here (fig. 10) is as follows:

The lowermost members represent partly the „graywacke"-sandstone, partly a conglomerate, described already by Bodenbender. Over the crystalline basement lies according to him a conglomerate with boulders of „schists", „graywacke", „carboniferous slate" and of granitic rocks. The hanging strata belong (according to Bodenbender) to „a gray psammite reminding of the graywacke" (of the Cerro Guandacol). This conglomerate may thence not be a basal conglomerate like that of the Cerro Guandacol profile, but may represent an inter-Gondwana erosion-hiatus, while detritus pro-

ducts of the lower Gondwana members are represented in the form of boulders. The „grey psammite“ of Bodenbender could not be the real „graywacke“ of glacial origion but must correspond to the upper, pale-coloured, psammitic layers of the lower Gondwana. Then follows over the „gray psammite“ a red, apparently triassic sandstone.

As to the writers studies of the strata in the profiles along the Quebrada Banda Florida and the dry gorge of the Rio de los Noques, running along the inside of the bordering sandstone mantle, the succession here is: over the crystalline rocks (quartzite schist)

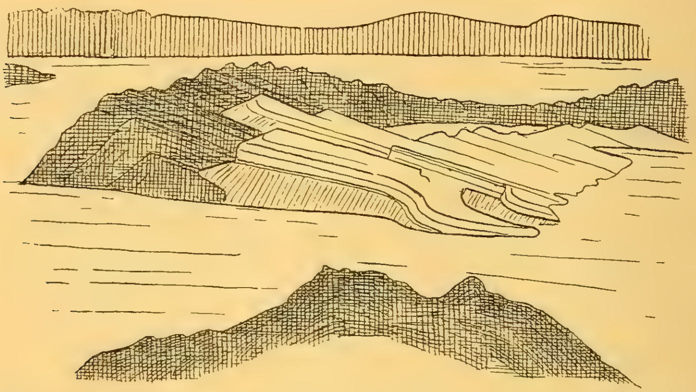

Fig. 11. An erosion remnant of red Gondwana sandstone, lying on a tilted crystalline basement block. Looking north from the Cerro Punta Colorada, eastern side of the Cerro Villa Union.

lies a pale yellowish sandstone as the lowermost member. The lithological character of this rock shows a great resemblance with the lower pale sandstones in the Cerro Guandacol profile. A distinct crosscurrent bedding reminds one much of the pelodite-sandstones in the classic profile at Jachal, containing small scattered boulders too. This sandstone is succeeded by a pale brown sandstone of psammitic character, overlaid with a mighty, very coarse conglomerate of dark brown colours. The boulders of this conglomerate, well waterworn and lying stratified with sandy interstratifications, all consist of old crystalline rocks. Upward follows then a mighty

series of red and brown sandstones of apparently triassic age. These last named strata form the very bulk of the Cerro Punta Colorada, as the name also shows. In the profile of the Quebrada Banda Florida only the red triassic strata are visible. They rest directly upon the crystalline basement, a circumstance met with in some other parts of this area too (fig. 11). This lack of the lower Gondwana in some strongly limited parts may be explained as the result of an incomplete inter-Gondwana erosion.

The „intermontane sandstone zone“.

A great variety of the continental strata is exposed in a long, strongly dislocated zone, running NNE—SSW through the whole country, and called here *„the intermontane zone“*, because it lies for a considerable part of its length between high mountain blocks and is intensely pressed together between them (see the geological map). The northern and southern extreme ends of the zone are somewhat difficult to fix. It may, however, be stated, that the zone to the southwest passes into the Precordilleran tertiary structure mapped by Rassmuss, while to the north, according to the map of Brackebusch (1891) and W. Penck (1920), the same zone seems to continue in the mountains of the province of Catamarca, following the Valle Hermoso. This zone is a very remarkable tectonical feature of the region. It represents, as shown later on, a subandean, tertiary, tectonical phenomenon, not found in the area of the true pampean sierras. In the present chapter, however, may be described only the lithological characters and the stratigraphical relations of the rocks.

The basal layers of this zone are visible only in two localities: 1) in Carrizal, situated between the Cerros de San Antonio and the Cerro Villa Union, and 2) at the Puesto Altillo NW from Maz. At Carrizal the relations are as follows: over an opturned mica schist complex with limestone layers lies a greenish conglomerate, composed of well rounded pebbles with soft green-coloured cement

mass. A stratification may be observed in the conglomerate showing, that the layers have turned vertically. To the west, that is upward in the profile, the conglomerate changes into a graywacke like the rock from Agua Blanquita. All the pebbles in the conglomerate are composed of crystalline rocks. Probably the conglomerate has a glacifluvial origin. Farther to the west no continuation of the profile is seen, because this whole outcrop lies as an isolated sunk remnant in the crystalline basement. Some engl. miles to the west there runs the eastern cuesta of the Cerros de San Antonio, composed of strata of the higher continental series, but without connection with the graywacke at Carrizal.

The above-mentioned cuesta of the Cerros de San Antonio shows at the base, composed of the same mica schists as at Carrizal, a graywacke rock like the former (well visible in a locality to the NW of Carrizal). Here, however, the graywacke has been extremely crushed by the tertiary movements. This rock is succeeded upward in the bluff by reddish and brown coloured sandstones with gently westward dipping layers. These are not torn as the graywacke, a circumstance which may be explained only by way of assuming a special tectonical phenomenon (see later on).

In the other locality, where the bottom layers occur, at the Puesto Altillo, situated on the eastern border of the intermontane zone in the southern part of the Cerro Potrero Viejo, no graywacke nor conglomerate occurs, but a yellowish sandstone of lower Gondwana character. The sandstone lies immediately over the crystalline basement, separated from it only by a thin sheet of a conglomeratic psephite. The sandstone contains regular interstratifications of a clayish slate. The thickness of this series is quite considerable, probably many hundred meters. The whole complex is strongly folded as consequence of the tertiary movements (in connection with the formation of the intermontane zone). The best exposures are visible not in the very zone, but aside from it, on the eastern slope of the southern part of the Cerro. On the very border, marked by a fault,

the sandstone and the slate of the zone have been intensely torn to a mylonitic mass of grayish colour. Following the fault farther northward in the direction of the Corral Martinez (lying on the eastern border of the zone) there always meet the same lower Gondwana rock series, downpressed and torn along the dislocation line. In some parts, however, the rocks have remained more unbroken and there the original lithology can be studied. In the vicinity of the Corral Martinez the writer has observed a vertically inclined part of a clayish slate, apparently a pelodite. The rock exposes (reminding of the quaternary banded clay in the Baltic basin of Fennoskandia) a conspicuous alternation of clayish and sandy layers in quick succession. In the sandy layers, (corresponding to the „summer"-deposits) I discovered carbonized remains of plants with an air of a *Gondwana flora.* Thinned and torn coal seams are outcropping some hundred meters to the south of this locality.

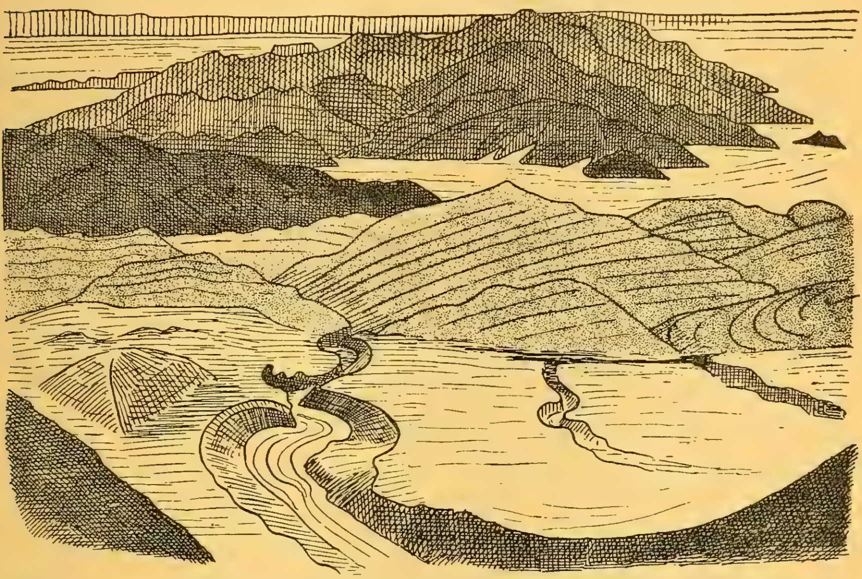

Fig. 12. The „intermontane sandstone zone" (dotted), strongly dislocated. In the background the Cerro Villa Union. Sketch from the eastern slope of the Sierra de Umango ridge, toward the SE.

The coal is mingled with sandy matter. The yellowish sandstone at Altillo contains on the bedding planes abundantly *Cruziana*-like figures.

The pale yellowish sandstone and the clayish interstratifications do occur only along the eastern border of the whole intermontane zone. The principal mass of the filling sediments are younger sandstones of various colours (cinnabar-red, and also white, chocolate-brown, pale brown). The stratigraphical succession of all these layers is quite difficult to state, because the tertiary movements have resulted in a number of strong folds and faults (see details under the tertiary tectonics). The elder members are, as seen, the pale yellowish sandstone and clayish slate with the coal seams. The crom-red sandstone of triassic(?) age, succeeding these beds in the slope of the Cerro Villa Union, seems to be lacking here, while some apparently younger brown beds develop a great thickness. Upward these gradually change into pale brown sandstone beds. These sandstones have a distinct continental littoral character with sun-cracks and ripplemarks on the bedding planes. The upper, paler variety contains some thinner conglomeratic layers. This sandstone occupies the western border of the zone and *is overthrust from the west* by the great Sierra de Umango fault block. On the very gliding plane there are, however, some small remnants of a crom-red sandstone, possibly the last remnants of the triassic (?) sandstone. The writer is inclined to consider the cinnabar-red sandstone to the east of the brown one as a younger one (cretaceous?).

An excellent cut through the whole breadth of the zone may be studied in a river gorge between the Jaguel bolson and the Vinchina valley. Here the „intermontane zone“ lies outside the mountain blocks and plays the part of a ridge or a dividing crest-line between the two depressions. Its eastern flanc consists of a more than hundred meters high bluff of some sinuous trench and can be followed from the northern end of the Cerro Potrero Viejo NNE-ward into the Valle Hermoso. The strata forming this bluff are

almost exclusively brown sandstone with small outcrops of an underlying red sandstone at the foot of the ridge. The brown layers lie in quite an undisturbed position in this profile, but soon they incline to the west, as shown in the transverse quebradas.

The river gorge between the Jaguel bolson and Vinchina (Rio Jaguel) reveals, going *westward,* the following profile:

The brown sandstone layers, outcropping in the bluff at Vinchina in an almost horizontal position with red layers at the base, dip, as stated, westward with gradually increasing gradient. Simultaneously the chocolate-brown colour of the rock changes into a pale brown one, but of similar lithological character as the former. Further to the west, the consistence of the rock, however, becomes softer. The dip then attains its maximum (about 45° W) and remains so in the rest of the profile (see further on).

This apparently quite uniform sedimentary series is overlaid with a mighty mass of surely younger strata of much softer consistence. These lie in conformity over the older, but are separated from them by a slight conglomeratic layer. The younger strata are of some different colours, pale salmon-red, or pale brownish, and often carry interstratifications of conglomeratic layers, attaining sometimes a considerable thickness. The consistence of the strata generally changes towards the west to greater softness. The dipping angle is always the same, 45° W. No doubt the soft series belong to young geological horizons (cretaceous-lower tertiary?), while the underlying sandstones are of the upper „Paganzo" series. South off the described profile the soft strata are with strong unconformity overlapped by a young conglomerate (late tertiary?), described on pages 113—115. Also to the north the same overlap can be observed, as it seems, on a much greater scale.[1]

The westward dipping strata of the zone disappear swiftly under the modern accumulations of the Jaguel bolson.

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[1] This observation was made only by field-glass.

At the southern end of the Sierra de Umango ridge the „intermontane zone“ shows a remarkable virgation. The western half of the zone bends into a sharp curve to the west along the southern head of the „crystalline“ mountain block, while the eastern half continues in southerly direction to the Precordillera of Guandacol, here passing over into the tertiary structure. Between these two branches lies the tectonical throw of Nacimientos -- Zapallar, filled out by dislocated, young tertiary gravels.

The eastern branch has entirely the same appearance as the just described ridge between the Vinchina valley and the Jaguel de-

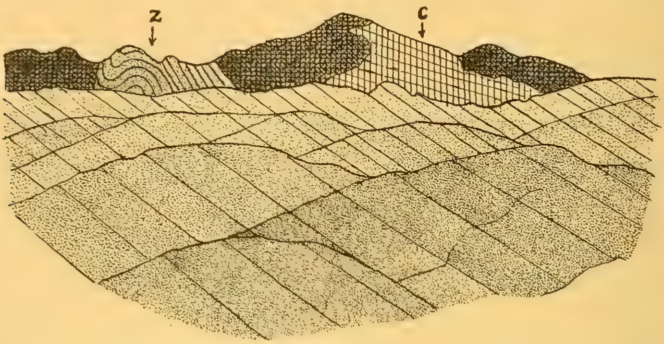

Fig. 13. Tertiary arenaceons strata dipping W to the N from Sierra de Umango, at the E border of the Jaguel bolson. S. U. in the distance. Z = intermontane zone with folded sandstones. C = young conglomerate in horizontal position.

pression. The Cerros de San Antonio, as this southern ridge has been named, forms too a high bluff of several hundred meters to the east running SSW and also almost S, at the same time bordering the Zapallar depression from the Carrizal valley train to the east. The strata here show, like these in the northern ridge, a generally increasing dip towards the west, while the lithological character of the strata changes getting a softer consistence and a paler colour. The bluff on the eastern side shows the same brown, slightly disturbed layers as in the ridge to the north of the mountains (the stratigraphy of this bluff has been already more closely described on page 81). A good cut through the whole ridge can be obtai-

ned by following the way from Zapallar to Guandacol along the crosscutting Quebrada de la Troya, reminding much of the above named gorge of the Rio Jaguel in the northern ridge.

The strata in this profile dip under several angles. The river *upward*, i. e. from the eastern mouth of the Quebrada, where the great bluff runs, there are first the brown, slightly disturbed sandstone layers. They dip gently westward, and at their base red layers are visible, exactly as at Vinchina. Along the river gorge upward one observes, that the dipping-angle of the brown layers gradually increases and that the position finally becomes vertical. Further upward the strata are again less steeply inclined and simultaneously they change their lithological aspect and become softer and more pale-coloured. The general strike is NE—NNE.

The westward bending branch of the zone is principally composed of brown sandstones with a substratum of crom-red sandstone. This last named is doubtless the lowermost horizon here, because it lies in a sedimentary contact directly upon the crystalline basement, as seen on the southern slope of the Cerro Cordobés. Upward in the profile the brown sandstone passes into a pale brown one exactly as in the last described profile. These pale-coloured strata are outcropping on the inner border of the Nacimiento's depression.

Summarizing the composition of this remarkable structural feature in the Umango area, called the „intermontane zone", may be stated, that this part of the continental sediment cover, strongly pressed during the tertiary diastrophism and downfolded between basement-blocks, shows quite a uniform composition: chocolate-brown and pale-brown sandstones dominate, the former occupying the eastern, the later the western part of the zone. Transitions exist between these two members. A crom-red sandstone occurs as small remnants in thinner zones or as basal layers of the series. Also a cinnabar-red and a white sandstone are seen in one locality. In the northern part of the zone, where this has a considerable breadth,

the upper, pale sandstone is concordantly overlaid with soft younger strata, not represented in the very "intermontane" section of the zone. In this section a complicated tectonic is developed, with folds and overthrusts, but the northern and southern continuations show a simple dip toward the west, a monoclinal structure. The age of all these layers shall be discussed later on.

Small sunk sandstone masses in the basement.

Limited areas of sunk or down-thrusted sandstone remnants occur in many parts of the Umango area. Because these occurrences lack every relation to the other ones of the continental cover, it is a difficult task to fix their real stratigraphical position.

First is to be mentioned a somewhat narrow, but quite a long zone of crom-red sandstone, running along the western foot of the main ridge of the Sierra de Umango and with a northeasterly trend crossing the same ridge in its lower, northern part. Finally the zone flows together with the intermontane zone (Quebrada Salto). The red sandstone here is not only deeply downfaulted between steep walls of the crystalline basement, the strata stand also vertically in the greater part of the zone, or are laid into folds by a thrust movement from the west (see the tectonics). The lithological habit of the sandstone is very a similar one to that of the upper Gondwana red layers in the slopes of the Cerro Villa Union. Also characteristic basic lava sheets are seen in these layers. The steeply inclined strata are discordantly overlapped with a coarse conglomerate (description of the locality on pages 113—115) and this sediment conceals to a considerable extent the red layers. Because the most interesting tectonical phenomena are visible in the vicinity of the Puesto Pirca (at the western foot of the mountain ridge), the zone may be called in the following chapters „the Pirca zone".

Other similar sandstone remnants in the form of longitudinal throws exist in the Quebrada Puesto Quemado, at the northern end of the Cerro Cacho and also at the very western border of the

Umango crystalline complex, on the watershed between the Quebrada Piedra Pintada and the Quebrada Cacho. In the former locality an overthrust from the west is to be noted and also dynamic phenomena. Here the sandstone is of red colour and carries concordant sheets of a basic tuff. Conglomeratic layers do also occur. In the latter locality the red sandstone layers stand vertically between vertical crystalline schists on the eastern side and strata of a graywacke and conglomerate series in similar position to the west.

At the western entrance of the Paso del Cordobés (Quebrada del Cordobés) there are, going east, on the left hand a pale yellowish sandstone lying almost in a horizontal position against the mountain slope, consisting of old crystalline rocks. The sandstone has purely white shades and contains conglomeratic interstratifications. The whole character shows a similarity to the lower Gondwana. On the right hand there is a steep, high wall of old crystalline rocks, the sandstone remnant is thence evidently downsunk and preserved here in spite of the great absolute height of the locality.

At the eastern foot of the Cerro Villa Union I observed on the trail from Villa Union to Maz a red sandstone immediately at the crystalline rock-wall, well exposed in the quebrada-profiles. This small outcrop is evidently the only visible remnant of a vast sunk sandstone area, occupying the floor between the named Cerro and the hills of Las Ramaditas and covered with the mountain gravel sheets. To which extension the lowland to the north from here may have a sandstone basement cannot be determined, because the alluvial fans from the mountain to the west cover all this ground.

The clastic complex west off the Umango area.

As has been already stated, the Umango-Cacho crystalline basement complex is bordered to the west by a great fault-line running north and separating it from an extensive series of steeply inclined c astic strata, composed, as observed, essentially of a graywacke-like

sandstone in regular alternation with quite a coarse conglomerate, containing well waterworn pebbles. At the fault-line itself these layers stand vertically, but to the south their position becomes more gentle-dipping with westerly inclination, while to the north, on the western border of the Jaguel depression, the dip is toward the east. The longitudinal extension of these strata reaches probably far into the Catamarca mountains, and southward at least to the northern head of the Precordillera of Guandacol.

There are following mountains composed of these rocks: from north to south the Cerro Punta Negra, the Cerros de Agua de la Piedra, the Cerro La Estaca and the eastern part of the Cerro Descubrimientos. The general strike of the strata is to the north, but a trend toward the northeast is observed in the northern part of the zone.

The zone marks the eastern border of the Cordillera in these regions, except to the west of the Cerro Cacho, where the first ridges built up by these series still belong to the topographical unity of the Cerro Cacho. Then follows to the west of these ridges the Pampa de Leoncito. Some small hills there rise over the gravel plains of this plateau and are composed of the clastic strata in question. The Cerro de Leoncito, bordering to the west the named pampa, is, however, differently composed, as is seen already from a greater distance. This region was studied by Rassmuss.

The sandstone-conglomerate complex lacks every lithological similarity with the continental series of the Umango area. It is considered by Rassmuss of Gondwana age[1]. In any case the strata are of postgranitic age, because they dont show any influence of granitic intrusion, which outcrops in the immediate vicinity, amidst the Cerro Cacho crystalline schists. The strata have a purely clastic habit. The concordance betweem the schists and these strata is thence only a tectonical juxtaposition of tertiary age, probably of a similar kind as the „conformities“ between schists and

[1] Verbal communication.

the continental strata on the Nevado de Famatina, mentioned by Stelzner and Bodenbender (see the page 59).

The Pagancillo lowland and the Vinchina valley.

About the stratigraphy of the vast, sunk area of the Pagancillo lowland I have made but few personal observations. According to Bodenbender (1911) the whole interior of this area is occupied by tertiary strata, lying over a basement of cretaceous sandstone, outcropping along the borders of the depression, where upbending phenomena are seen. Also to the north, in the bottom of the Vinchina valley, the cretaceous strata are exposed.

Good profiles can be studied along the course of the Rio Bermejo to the south from Maldonado and especially in the traversing quebrada of the Paso de Lamar. This water gap crosses the sandstone ridge, which forms the southern (southeastern) prolongation of the Cerro Bola and is known as the Lomas Coloradas with their highest point, the Cerro Colorado. To the south of the *paso* there rises another mountain, the Cerro Rajado, the northern head of a long sandstone cuesta, the Sierra del Valle Fertil.

The profile in the Paso de Lamar begins in the west with pale greenish sandstone layers with numerous basic sills, according to Bodenbender (1911) of rhaetic age. The strata dip toward the east, but many irregularities may be observed, as flexures and a local dôme-shaped uplift. Red sandstones of considerable thickness changing upward into brown layers, lie with a complete conformity upon the rhaetic strata. These strata are considered by Bodenbender (1911) as of cretaceous (and jurassic?) age. The Rio Bermejo upward, out of the *paso*, in the direction of Maldonado, the brown-red sandstone forms the whole underground, always dipping under the same angle to the east, soon covered with the old gravel sheets of the Pagancillo lowland. In the vicinity of the river bed the sandstone is well exposed, partly as isolated erosion remnants of peculiar shape. The slope of the Cerro Colorado to

the west is barren and composed entirely of these sandstone layers.

On his map from 1911 Bodenbender has indicated the existence of tertiary strata along the course of the Rio Bermejo south from San Isidro (Paso de Isidro). I have, however, on this route seen only the above named red sandstone layers, exposed already in the described profile of the Paso de Lamar.

The writer has personelly traversed only the northern part of the Pagancillo lowland, between Villa Union and Puerto Alegre. Here the road passes over a hilly landscape, composed entirely of soft younger strata. While the small meseta hills in the vicinity of the Villa Union consist of the red (cretaceous?) sandstone dipping gently eastward, the road leads further to the east into the above named soft-rock-terrane, known as the Lomas de Villa Union. The topography here has the character of „bad land“ and the strata are always pale yellowish or orange-coloured and of very soft consistence. They would probably have been levelled already by the erosion, if they did not carry a horizontal covering sheet of hardened diluvial gravels. The dip of the strata is constant, about 45° W. Conglomerate beds are frequent. The series corresponds to the Calchaqui formation.

From the Puerto Alegre may be observed (with field glass), that the numerous terrace-remnants (high diluvial terraces) on the western slope of the Serrania de Famatina (the cuesta bordering the Pagancillo lowland to the east) are composed of the same soft pale-coloured layers as in the Lomas. Here the dip is, according to the profiles of Bodenbender (1911), steep toward the west. The terrace planes therefore cut obliquely across the edges of the strata.

At Puerto Alegre in the erosion profiles of the dry current bottom is seen a series of vertically tilted layers of dark brown sandstone and conglomerate. Then follows to the east the red sandstones of the „Paganzo“, disappearing toward the Famatina mountain abrubtly

on great fault walls. The strata are tilted here in many directions.

To the south of the Pagancillo lowland we meet with the great sandstone terrane of the Campo de Talampaya, consisting, according to Bodenbender's map (1911), of cretaceous beds.

b) SUMMARY OF THE STRATIGRAPHY.

Above is characterized the lithological habit and the mutual relations of the continental strata, covering the old crystalline rocks. An attempt to arrange these strata into a chronological succession from the base to the top and a trial to separate some greater sedimentary divisions and to determine their age may be convenient. By the almost complete absence of fossils this task will naturally be only a very approximative one, based, as it is, on the lithological and tectonical peculiarities, and to some degree on the behaviour of the divisions to these in the surrounding regions.

The first question considering the age of the continental strata is that of the age of the *basal plane*. In other words: how old is the cutting plane in the Umango crystalline basement, supporting all the clastic continental rocks and their effusives?

In the province of La Rioja aside from the Cordilleran chain there is a considerable number of known occurrences of *plant-bearing lower Gondwana strata,* forming the basal layers of the continental series and lying with a great unconformity over the steeply inclined and mostly granite intruded crystalline schists. The lower Gondwana occurrences, consisting of yellowish and gray sandstones with coal seams and often with a basal conglomerate, are:

1. Cerro Bola.
2. Cerro Villa Union (Cerro Guandacol, profile descr. page 68).
3. Nevado de Famatina:
    a) Quebrada de Tambillos.
    b) Carrizal.
    c) Potrero de los Angulos.

4. Sierra de Sañogasta (Cuesta de Miranda).
5. Sierra de Velazco (Saladillo).
6. Sierra del Vilgo (Amanao).
7. Sierra de los Llanos. (Nacate, Malanzan, etc.).

According to the plant remains from several of these occurrences (Kurtz and Bodenbender) they belong to the Karharbari horizon of India or to the Ecca series of South Africa. The specimens belong to a typical *Glossopteris* flora (lower permian). Under the coal bearing sandstones lies, as said, in many parts a boulder bed of basal character, noted already by Bodenbender (1896) in the

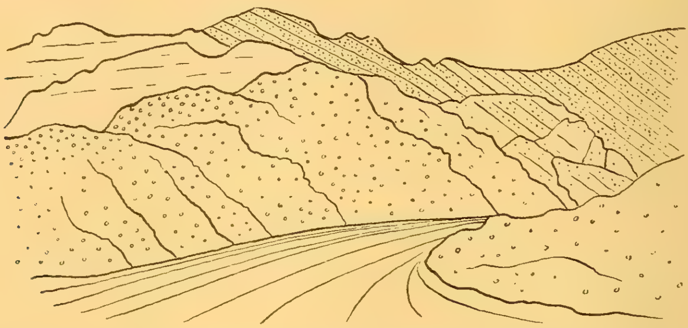

Fig. 14. The tillite occurrence at the Agua Blanquita. Small circles signs: tillite. To the right in the background sandstones of the lower Gondwana. The white part to the left is the crystalline basement. Looking east.

Sierra de los Llanos, and since encountered in most of the above enumerated localities. The conglomerates are not yet more closely studied, therefore but little is known about their lithological character. Keidel is, however, of the opinion, that they are all of a glacial origin as the conglomerate of permian age more closely examined by him in the profile of Jachal in the Precordillera of San Juan (Keidel 1914). Probably they all correspond to the lower permian glaciation and are of the same age as the Talchir in India and the Dwyka conglomerate in South Africa. As found above the conglomerate and the graywacke outcropping in the profile of the Cerro Guandacol show a glacial (tillite) character too. Similar rocks also do occur in the Famatina mountain.

It may also be assumed, that the lowermost horizon of the continental series in this part of the Republic is represented by a lower permian glacial formation. Probably this was deposited over a perfectly levelled surface, consisting of the crystalline schistose and granitic rocks. Already above is stated, that the degradation process down to this surface apparently was going on during a long lasting erosion period,[1] because abyssal rocks are exposed in the surface to a vast extent. This erosion work was naturally accompanied by an uplifting movement of the ground. The plutonic metamorphism, the results of which are now exposed in the surface, must thence have occurred a long time before the lower permian.

The basement cutting plane must thence at least be of pre-permian age.

In the Umango area there are remnants of the lower permian tillite, as said, only in the Cerro Guandacol profile and at Carrizal. In all the other localities, where the continental strata are resting directly on the basement, either the yellowish sandstone lies lowest, or the red triassic (or cretaceous?) one. The tillite beds (conglomerate and graywacke) have thence been extensively destroyed by erosion before the sedimentation of the red beds, or even before the formation of the yellowish sandstone and shales of the lower Gondwana. These last named carrying in some parts remains of a *Glossopteris*-flora[2] (Cerro Bola, Cerro Guandacol, Corral Martinez) are in the Umango area generally of no great development, propably destroyed to a large extent by at least a pretriassic denudation. The mightiest layers do occur in the Cerro Guandacol profile, and a remarkable development is also visible on the southeastern slope of the Cerro Villa Union. No other occurrences of these

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[1] If this deeply reaching erosion proceeded in all parts of the pampean sierras as one phase or was interrupted in some regions by a period of diastrophism, is not closer investigated.

[2] According to Kurtz the species *Neuropteridium validum* should be characteristic of the lower Gondwana.

layers are known except small remnants on the Cerro Punta Colorada and the Cerro Potrero Viejo. On the Famatina side there are, however, several of this kind.

Over these strata follows *without unconformity* a series of cromred and upward redbrown sandstones with numerous conglomeratic interstratifications. Already long ago this series has been regarded by Bodenbender of triassic or Damuda age. The circumstance, that these beds lie in some parts directly over the crystalline basement, shows, that a pretriassic erosion took place, but without preceeding orogenetic movements [1], as is evident from the conformity between these and the underlying pale-coloured sandstones and slates.

The triassic red beds seems to have a considerable extension in the Umango area, although it is difficult to state if the strata in some parts really belong to the triassic. As shall be seen, the upper layers in the continental series have often similar characteristics.

The development of the red beds on the Famatina side is a considerable one, appearing in most „grabens" there and also on the crests up to great heights.

The fact that the conglomerate layers in these triassic and younger strata carry boulders of the old crystalline rocks indicates, that judging from the thickness of the layers the pretriassic erosion reached the crystalline basement in some parts to a greater depth.

The red beds change upward into brown sandstones of similar consistence. They seem to be of a considerable thickness. It is interesting to find, that the brown strata occur only in the „intermontane zone" to its whole length, but in no other part of the Umango area. For instance in the mighty succession of the Cerro Guandacol — Cerro Bola-profiles no brown beds are visible. But in the NNE continuation of the „intermontane zone" in the mountains

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[1] It may be spoken later on about the influences of the permian andean movements here. They are in fact very insignificant.

to the west of the valley of Fiambalá, province of Catamarca, Penck (1915) has really discovered similar beds (see later on).

The occurrence of the brown sandstone only in the intermontane zone may be explained in the following way: At the time when the zone in question was downfolded or downpressed (in miocene time?), the continental series in the area was much more complete than now. The late tertiary erosion had not yet to any greater extent worn away the upper members of the series. The brown strata extended still ower greater¦ areas. After these movements the late tertiary erosion destroyed all the brown layers, except where they lie safe in the longitudinal throws.

It is impossible to express any opinion[1] about the age of the brown beds. The observation may be stated, that in the profile between Vinchina and Jaguel they change upward gradually into pale brown sandstone like the rhaetic one in the Paso de Lamar, and that this later passes upward into softer, pale salmon and yellowish red sandy and conglomeratic beds of probably lower tertiary age. The brown layers expose at their base a substratum of red sandstone. Also on the southern slope of the Cerro Cordobés the brown layers show downward red and upward pale brown sandstones in conformity.

Surely rhaetic strata do occur in the Cerro Rajado at the western entrance to the Paso de Lamar, being here a northern continuation of the extensive occurrences in the Sierra del Valle Fertil, discovered already by Stelzner-Geinitz [Bodenbender (1911)]. These strata contain remains of *Thinnfeldia*. The rhaetic formation outcropping in the Paso de Lamar continues northward along the eastern side of the Cerro Bola. A farther extension of the rhae-

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[1] Penck (1915) mentions the occurrence of dark brown and redbrown sandstone series in the western Catamarca mountains, resting with unconformity (quasi conformity) over the „Paganzo“ sandstones. Because they carry andesitic tuffs and conglomerates, Penck regards their age as tertiary — that of the lower horizons as probably cretaceous. Judging from the lithological habit of the brown beds in the Umango area, a tertiary age seems there to be quite low.

tic strata in the Umango area seems to be doubtful; perhaps the pale-coloured members of the „intermontane zone" are of the same age.

The many rhaetic occurrences indicated on the map by Brackebusch (1891) from the Umango area are, as stated above, incorrect.[1]

Over the rhaetic beds in the Paso de Lamar follows concordantly the upper red sandstone perhaps of jurassic — cretaceous age, very similar to the triassic one [Bodenbender (1911)]. The great lithological similarity with the triassic sandstones makes it very difficult to judge about the age, especially regarding the small isolated remnants of such red sandstone, downfaulted into the crystalline basement. If the „cretaceous" occurrences indicated by Bodenbender (1911) from the eastern parts of the Cerro Villa Union are in reality all of this age, seems doubtful. For instance, the floor of the valley bottom in the vicinity of the Villa Union forms the direct continuation of the upbent strata at the eastern slope of the Cerro Punta Colorada and nevertheless the former are indicated as „cretaceous", the latter as „Paganzo".

Still younger strata, belonging to the miocene, etc. Calchaquí-beds („estratos calchaqueños", named after great occurrences in the valley of Calchaquí in the province of Tucumán) have developed on quite a considerable scale in the Umango area, where they occupy probably the greater part of the Pagancillo lowland. They also do occur in the tectonical depression of Zapallar to the west, so in the Jaguel depression too, where they *lie conformably over the older continental sandstones* (profile Vinchina—Jaguel). The Calchaquí-strata consist of a series of soft, pale yellowish, pale salmon-red and white nuancering sandstone-marls and conglomerates.

A coarse gray conglomerate indicating a sudden change in the conditions of sedimentation does cover with a marked overlapping unconformity these strata. This conglomerate is, however, of a small extension. All its pebbles consist of old crystalline rocks.

The probable stratigraphical subdivisions of the pre-

quaternary continental strata are shown in the following scheme:

	Overlapping the whole series:
Pliocene	Coarse torrential conglomerate (Puna gravels).
	Unconformity. Dislocations.
Miocene	Calchaquí-strata. Soft Sandstones, marls, conglomerates.
	Dislocations.
Cretaceous Jurassic	Brown, red and redbrown sandstones. Crossing veins of basic volcanics.
Rhaetic	Grayish and greenish sandstones and slates with coal seams and *Thinnfeldia*. Basic lava sills.
	Pale brown sandstones (rhaetic too?).
Triassic (Damuda)	Red and upward brown sandstones (triassic too?) and conglomerate beds. Concordant sheets of amygdaloide and dense melaphyric rocks. Gypsiferous fissures in the sandstones. Suncracks and ripplemarks on the bedding planes.
	Hiatus of erosion.
Permian	Grayish sandstones. Clayish slates alternating with sandstone beds and containing plant remains *(Neuropteridium)*. Coal seams.
(Karharbari)	Grayish — yellowish sandstones with alternating slates. On the bedding planes of the sandstones *Cruziana*-like figures.
	Local hiatus of erosion.
(Talchir)	A graywacke-like rock with scattered small boulders. No stratification (tillite). At the base a coarse conglomerate bed.
	Great unconformity.
Old palaeozoic	Basement of metamorphic schistose and eruptive-injection rocks.

C) THE PERMIAN OROGENETIC PHASE.

Dynamical influences in the Sierra de Umango schist area.

According to the investigations by Stappenbeck (1910) and the latter more detailed ones by Keidel (1914), the eastern bordering zone of the middle part of the Argentine Cordillera is tectonically composed of a pretriassic or permian folded structure, capped in a great unconformity with the triassic red beds. These old folds are, as Keidel has stated, of an „alpine" character with 'nappes de charriage' etc., indicating the existence at that time of a tangential orogenetic pressure from the west, possessing a much stronger character than later on during the tertiary diastrophism (see farther). This ancient folding zone, corresponding to the so called „Precordillera", extends from the vicinity of San Rafael in the south to the Sierra de Umango area in the north. The northern end of the folding zone is formed by the „Precordillera of Guandacol", recently investigated and mapped out by Rassmuss (1916). This part of the chain rises to the west abruptly up from the Guandacol valley floor. Northward it does not attain the Umango area, but is separated from it by tertiary dislocations. Therefore the Umango crystalline rock complex does not come into contact with the Precordilleran structure. At the western border of the Umango area, where it is topographically connected with the Cordillera, no Precordilleran structure appears, as seen above.

But it is evident, that the Umango area has at least in some degree played the part of a „Foreland" to the Precordilleran chain. It remains to consider to what extent the tangential movements in the Guandacol Precordillera have influenced the Umango block.

In the Cerro Villa Union, situated opposite the Guandacol Precordillera, the Gondwana strata, as has already been described above, are disturbed only by the tertiary movements. Also in other parts of the area, where the lower Gondwana still remains in position preserved from the erosion, there are same circumstances.

Consequently the pressure phenomena characterized on the fore-

going pages, do not belong to this phase, but to earlier and later ones.

As has been stated, the lower Gondwana strata in the Umango area are frequently lacking where younger ones exist and where the red triassic or even the cretaceous (?) beds lie directly over the crystalline basement. This circumstance indicates an erosion hiatus, *probably caused by the precordilleran* (permian) *tectonical influences.* During this time faulting movements seem to have occurred in the Umango area like those of the later tertiary time.

D) VOLCANIC ROCKS OF THE CONTINENTAL SERIES.

In the pampean sierras-area there are in the continental strata many occurrences of lava beds of different composition especially, as was stated already by Stelzner (1876—85), in the rhaetic beds. These volcanics are nearly all contemporaneous with the intervening strata, which is evident from the many amygdaloide rocks and the ash beds. — From the Umango area and the surrounding regions also many outcrops of similar volcanics are known, principally through Bodenbender's investigations.

All the continental volcanics in the Umango area are of a very basic character. The most common types are melaphyre, porphyrite and spilite. Aphanitic varieties do also occur abundantly. The corresponding tuff layers are partly clayish and very decomposed, partly large-grained, or even agglomeratic.

But little can be stated about the occurrence of *volcanic centres* in the Umango area. The writer has discovered in some parts of the crystalline basement crosscutting veins of basic lava rocks, probably corresponding to „furnish or feeding channels“ of the basic lava outpourings. At the eastern foot of the Cerro Villa Union there is seen a remnant of a volcanic neck, setting up through limestone. In the sandstone terranes there are sometimes accumulations of lava to a degree as to form doubtless volcanic centres. For instance the volcanic mass of the Cerro Rajado at the western entrance of

the Paso de Lamar, described already by Bodenbender (1911), has clearly furnished all the material of the numerous lava intercalations in the rhaetic strata, which the neck is cutting through. In the Campo de Talampaya to the south from the lowland of Pagancillo there is a vast accumulation of aphanitic and spilitic lavas, already mentioned by Stelzner (l. c.).

The petrographical descriptions of the volcanics from the pampean sierras' continental strata are not abundant. Stelzner (l. c.) says, that these rocks are, when melaphyric, composed of a plagioclase and a purplish augite. According to this author ophitic structures are quite scarce. Olivine occurs sometimes, associated with picotite. Magnetite is found frequently. The vesicles of the rocks, representing ancient superficial flows, are filled with calcite or viridite. Sometimes they are also empty.

The petrographical data published by Siepert (1894) from the material of Brackebusch concern only to a small degree the Sierra de Umango area. Siepert divides the rock types into „Diabases" and „Melaphyres". Regarding the geological age of the rocks, the latter name is to be preferred.

Specimens of the continental volcanic rocks, collected in all parts of the area investigated, may offer quite a complete picture of the whole effusive series, corresponding to the length of the continental period in these regions. Besides a description of the concordant beds of superficial lavas and tuff layers here follows a such of a great number of effusive rocks, whose age in many cases cannot be exactly fixed, i. e. quartz-porphyries, lamprophyric rocks, basalts and some leucocratic rocks of dike appearance. A description of the tertiary volcanics of some isolated occurrences will then follow.

a) „CONTINENTAL" LAVA ROCKS.

The spilitic types are the most common among this class of rocks. The dense mass is generally of a darkbrown colour, and calcite- or quartz-filled vesicles are dispersed therein as numberless white

spots. There is also a porphyritic development containing conspicuous plagioclase phenocrysts. The spilitic rocks occur principally in the triassic red beds, while the dense types are met with in the rhaetic and younger strata.

The lava rocks have all been disturbed by the tertiary tectonical movements, but only exceptionally they are crushed.

The mineralogical composition of the different types of rocks do not reveal any special combination. The melaphyric facies is always bound to ophitic structure and richness in ferric oxyde. The ore impregnation increases incidentally to such a degree as to obscure, especially by pronounced weathering, the original mineralogical composition and structure. The plagioclase laths, however, are often clear and lie thence in an almost opaque mesostasis of the ore pigment.

Description of types.

In the tilted red sandstone layers of upper Gondwana age along the southeastern slope of the Cerro Villa Union already from a greater distance there appear black, concordant lava sheets carved out by erosion. In handspecimen the rock is of a highly ferriferous, spilitic type. The abundance of weathered ferric oxyde conceals the microscopical structure, except the plagioclase laths. These lie isolated in the dark mass, producing a porphyritic structure. Albitic twins are scarce, and the extinction is wandering. An incomplete decomposition to sericite may be observed almost in all individuals. Some of the vesicles are filled with quartz or calcite.

Another sheet of the same sandstone series represents a dense, dark grayish melaphyre. The rock contains abundant plagioclase of imperfect lath-form in ophitic arrangement. The albitic twins are indistinct. Besides ferric oxyde, partly as secondary product, there are no mafic minerals. Among weathering products calcite is very abundant. Also small spots of chlorite are visible. The abundance of the feldspar produces the grayish colour of the rock.

Many dark concordant lava sheets are met with in the Tambillos valley in the variegeted continental sediments in different grade dislocated and occupying the whole valley floor. A melaphyre lava in the vicinity of the Puesto Tambillos shows microscopically a great abundance of ferric oxyde. This matter forms an opaque mesostasis between the feldspar laths. Cavities are scarce.

On both sides of the entrance to the Quebrada Arroyo La Totora southward off the Cerro Cordobés (opposite the Cerro Avalao) a series of red sandstone layers, dipping southward and reposing directly on the crystalline basement, contain in their lower part concordant sheets of an aphanitic melaphyre partly of amygdaloide development. The structure being a typical ophitic one shows a network of fine plagioclase laths, slightly albite twinned. The small-granulated augite is yellowish-grey; sometimes it is developed in larger, idiomorphic individuals. The interstices are filled with glass. Ore dust is quite abundant, partly associated with a greenish-yellowish serpentine and thence evidently an alteration product of olivine.

To the north of Nacimientos on the right hand of the way to Tambillos rocks of red sandstone, dipping southward and forming a westward continuation of the mantle at the entrance to the Quebrada La Totora, contain a concordant basic sheet of a somewhat different aspect. The rock is dark brown and porphyritic with a dense mesostasis. The distinct phenocrysts of plagioclase are pale greenish and isometric. The structure is closer andesitic than melaphyric. The feldspar phenocrysts show the zonar polygones well developed with a maximum extinction angle (on cuts perpendicular to M and P) of $+25°$, i. e. $Ab_{60}An_{40}$. The groundmass consists of small feldspar laths and minute ore grains, cemented by intensely pigmented glass. The numerous cavities of the groundmass are filled with calcite or viridite in radiating aggregates. Isolated grains (relics of augite) do occur too.

Near to the Pirca post in the above described small dislocation

zone the tectonically downfaulted red sandstone, running along the western foot of the Sierra de Umango ridge, contains a concordant sheet of a highly amygdaloide, dark lava rock. All the well rounded cavities are filled with calcite. The amygdules, closely packed together, lend to the rock in handspecimen an almost oolitic habit. The rock mass between the amygdules is a very fine grained, ophitic melaphyre, very rich in ore minerals, which form an opaque mass between the minute feldspar laths. These are quite altered and pigmented by ore dust, and their optical characteristics could not be fixed.

In the Paso de Lamar the series of rhaetic sandstones at the base of the profile contains a great number of basic lava intercalations. They are, according to Bodenbender (1911), of greenish melaphyres. There is also an abundance of the same rock in the rhaetic strata in the Cerro Mogote to the south. This lava rock was petrographically described by Siepert (1894). The structure is a distinct porphyritic one with isometric phenocrysts of plagioclase, showing partly a zonar structure. The groundmass contains small laths of plagioclase, showing flow arrangement. Minute grains of iron oxide are scattered over this mass. A pseudomorph of calcite after augite is occasionally seen. Serpentine also appears, probably as alteration product of the original olivine. Regarding a more detailed mineralogical description I refer to the quoted paper by Siepert.

In the cretaceous red layers, lying immediately over the rhaetic strata in the above named profile, some crosscutting dark eruptive veins are seen. In handspecimen this rock is dense but carries cavities. Microscopically it reveals a minute ophitic structure, composed of plagioclase laths, ore grains and calcite. Also opaque spots of ferric oxyde are abundant, evidently of secondary origin as the calcite, and visible also in handspecimen. There are no mafic minerals preserved. The cavities are filled with calcite. Seen between crossed nicols the rock is quite dark, probably depending on a not inconsiderable amount of glassy substance. The age of these cutting

veins is perhaps cretaceous, judging from the development of amygdules.

In the Quebrada Puesto Quemado, on the northern slope of the Cerro Cacho, there appears as intercalation in the strongly downpressed sandstone remnant a dark volcanic sheet, in handspecimen difficult to determine. Microscopically it is of a typical mylonitic structure. The principal minerals are plagioclase, crushed into fragments, and ferric oxyde, filling the interstices between the fragments. The latter is probably always of secondary origin. Doubtless, the original rock was a melaphyre, all mafic components of which having been transformed into mylonite and altered to a ferri-pigmented mass. The habit of the sandstone containing the volcanic layer indicates also, that strong dynamical influences have overgone it.

To the north from Tambillos, the huge masses of volcanic rocks are generally of quite a different composition in comparison with the above described rock series. It is highly probable, that the former belong to a much later volcanic activity than the latter ones, and therefore their description may be postponed. However, in the vicinity of these volcanic masses there occur in the red sandstone beds belonging to the extensive series of the Tambillos valley floor some mighty lava beds of amygdaloide character, well visible on the path from the Puesto Tambillos up to the Puesto Umango.

b) „CONTINENTAL“ TUFF-LAYERS.

In the description of the profile at the western side of the Cerro Guandacol is made mention of the occurrence of a mighty tuff layer of dense habit and chocolate-brown colour, concordantly intercalated between the lower and the upper Gondwana series. The layer was already observed by Bodenbender (1911) and is indicated in the profile on page 69. In handspecimen the tuff rock is completely dense and of no conspicuous stratification. The humid rock smells clayish. Microscopically the rock seems to be very fine-

grained, although its intense pigmentation with an iron ore dust conceals to some degree the structure of the rock. The greatest part of the grains seems to be quartz. A clayish product occurs probably in the pigmented mass. This product of chemical decomposition may be regarded as a result of a weathering of the rock under humid conditions, subsequent to the deposition of the lower Gondwana layers. The tuff belongs to the first great volcanic phase during the continental period. Corresponding lava rocks are found farther to the northeast in a similar stratigraphical position (see page 99).

To the south of the southern end of the Cerro Villa Union there follows the great upbend of the Cerro Bola with the strata ranged in the same order as in the Cerro Guandacol profile. According to Bodenbender it appear here many volcanic intercalations (spilites), but also tuff layers. All these dark intercalations are well visible on the mountain slopes to the northeast and north.

In the syncline between the two mountains in the red sandstone beds there lie (near to Las Lajas) mighty volcanic agglomerates. These are mostly composed of angular fragments cemented by a dark mass of grayish colour (ash). The fragments consist of melaphyre of porphyritic structure and also of quartz. Microscopically the melaphyre seems to be very ferriferous, having almost an opaque groundmass.

From the last named locality some miles in the direction of Aguada de los Burros mighty series of red beds are outcropping [according to Bodenbender (1911) of cretaceous (?) age] containing a concordant layer of a dark finegrained volcanic rock. In handspecimen one detects small cavities. Studying the rock microscopically the principal part seems to be a glassy substance with numerous inclusions of angular quartz grains. The glass mass is very porous and rich in ferric oxyde, forming irregular spots. The quartz grains originate doubtless in the neighbouring sandstone, and the glassy tuff was thence evidently formed simultaneously with the sandstone.

In the glassy mass there are also fragments of a dull feldspar and of calcite. The calcite also fills the cavities in the rock.

E) CROSSCUTTING ERUPTIVE DIKES IN THE CRYSTALLINE BASEMENT.

In different localities of the Sierra de Umango crystalline area there are many dikes mostly of porphyritic rocks and sometimes also greater volcanic masses cutting through the crystalline basement *without visible relation to the covering sediments.* Their age is therefore in many cases of a somewhat doubtful nature. In a few localities the dikes have been affected by the first tertiary movements. Generally these rocks are of a petrographical habit differing from the above described „continental“ lava rocks and show a more pronounced hypabyssal behaviour.

Quartzporphyry dikes in the Famatina assimilation zone.

On the western sides of the rugged crystalline foothills along the western slope of the Nevado de Famatina there appear a number of straight running dikes of brown-red colour. The position of them is remarkably flat. They show no relation to the old structure. In handspecimen the rock is dense, containing scattered minute phenocrysts of paler colour. Some quartz grains are also megascopically visible. In some veins the dense groundmass has a flow structure. The rock is a typical quartzporphyry with a granophyric, sphaerolitic groundmass, composed of quartz and a red-pigmented feldspar. The phenocrysts are to a greater extent of albitic character and thence give the rock a more keratophyric appearance. The quartz phenocrysts have nearly all strongly corroded contours. No signs of pressure are visible in the rock.

Lamprophyric dikes.

In his paper on the geology of the Nevado de Famatina Bodenbender (1911) mentions, that „lamprophyric dikes“ do occur in many

parts of this mountain. If this author may be correctly understood, rocks with name of „lamprophyres“ are partly younger crosscutting dikes, partly great inclusions in the batholith and thence elder than the granite. The latter types are probably identical with the above described amphibolite inclusions. There are seen but little of real crosscutting dikes of lamprophyres in this mountain, as far as I know.[1] The relations of these to the above described quartz porphyry (keratophyric) dikes have not been made clear by observations.

In the „abyssal“ part of the Cerro Cordobés there has been discovered a great number of lamprophyric dikes, independently cutting across the old rock members. In these dikes the rock is always dense and of black greenish colour. There appears a jointing, causing a partition into angular blocks. Microscopically it reveals a porphyritic structure composed of small phenocrysts of plagioclase and a groundmass of granular amphibole of green colour, intermingled with small feldspar grains. The plagioclase phenocrysts are not more closely determinable, because they are intensely altered. The amphibole has the ordinary habit. A parallel orientation of minerals in the rocks structure lacks completely, also every sign of pressure. The groundmass is more of a hornfels nature. It seems quite probable, that the rock belongs to the malchitic type (Rosenbusch). It is remarkable, that the amphibole is more abundant than the plagioclase and thence also more abundant than in the ordinary amphibolite.

There is in the limestone banks, occurring as concordant bands in the profiles of the Quebrada Cordobés (eastern slope of the Sierra de Umango ridge), a crosscutting lamprophyric dike, having in handspecimen a dense habit. By microscope one can see, that the structure is an ophitic one. The mafic mineral is an elongated augite, oriented in like divergent directions as the plagioclase laths.

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[1] From the collections of Bodenbender.

Also phenocrysts of this mineral are visible, with an idiomorphic development. The augite laths are elongated in directions vertically to the b-axis, reminding of the limburgite form of pyroxene and also of the salite form. The maximal extinction is about 45° in sections normally to b. All these augite individuals carry a darker border zone. The plagioclase laths are highly decomposed. In some parts there are pseudomorphs of fibrous serpentine, propably after olivine. Iron ore occurs quite abundantly as spots or elongated grains, being partly of secondary origin too.

In the granite-free zone, consisting mostly of quartzitic schists exposed in the Quebrada Salto in the northern part of the eastern slope of the Sierra de Umango ridge, there is a concordant dark eruptive dike. The microscopical structure is of hypabyssal habit, but the rock is very decomposed by formation of secondary minerals (calcite, chlorite, etc.). The principal components are plagioclase and a mafic mineral, but the latter only preserved as pseudomorphs. The former shows allotriomorphic, the latter idiomorphic forms. The tracks of the cleavage in the latter lead to short prismatic amphibole.

In the higher part of the Cerro Cacho on its western slope a melanocratic dike cuts across the granite intruded schists.

The principal minerals of this rock are plagioclase, very altered, and a greenish amphibole with slight absorption (actinolite) and without pronounced orientation. Quartz is present to a small amount, representing the last product of consolidation. Secondary minerals are calcite and sericite. Apatite and magnetite are present as small individuals. The rock seems to belong to the vogesite — odinite series of the lamprophyric group.

Basaltic dikes (melaphyres of the continental series?).

In different localities there are found basaltic dikes cutting across the crystalline schists. They are sometimes affected by the tertiary movements. Although the rocks lack every relation to the conti-

nental sediments, they can probably be regarded as allied with the volcanic series of the continental period, and may thence have played the part of furnish-channels to the lava sheets of this time. The microstructure shows an ophitic development, although signs of strong pressure often appear. The plagioclase has the labradorite characteristics. There is a pale purplish coloured augite which is generally granulated. Secondary minerals are common. Quartz occurs in small quantities, likewise magnetite and pyrite.

F) TERTIARY (?) VOLCANIC ROCKS.

From Tambillos to the north, up to the Umango highland ground, the passage goes through a hilly landscape of younger volcanics, situated on the southern border of the named upland plain (see the figure 15). These volcanics are not associated with the continental beds as those in the cases above described (continental lava rocks), but form an isolated area, limited by faults from the surrounding crystalline ground. The downwarping of this volcanic mass has also preserved it from destruction by the river erosion. As these rocks differ in geological and petrographical appearance from the continental volcanics, it seems probable that they belong to a much later volcanic activity and may be considered as contemporaneous with the tertiary andine outpourings of chiefly andesitic rocks.

The principal rock type of this volcanic series may be classified as a feldspar-porphyrite. In handspecimen it is a fine grained rock of a dark brown colour, carrying small feldspar phenocrysts with lustering cleavage surfaces. Microscopically there is an abundance of feldspar, not only as phenocrysts, but also as matrix component, where it is mingled with grains of iron ore. The feldspar phenocrysts have idiomorphic contours and develop a core of plagioclase and a shell of potash feldspar. The plagioclase is a sodic one. The groundmass feldspar develops minute tabular forms, divergently oriented. They do not show any albitic twins, but undula-

ting extinction. Evidently it is a more acid (trachy-) andesitic rock.

Another rock associated herewith, is a reddish brown porphyrite containing pale phenocrysts of feldspar. Microscopically it reveals abundantly potash feldspar as phenocrysts and also as greater fragments. The groundmass is composed of a glassy (?) substance with inhomogeneous pigment of iron ore dust. The glassy residual

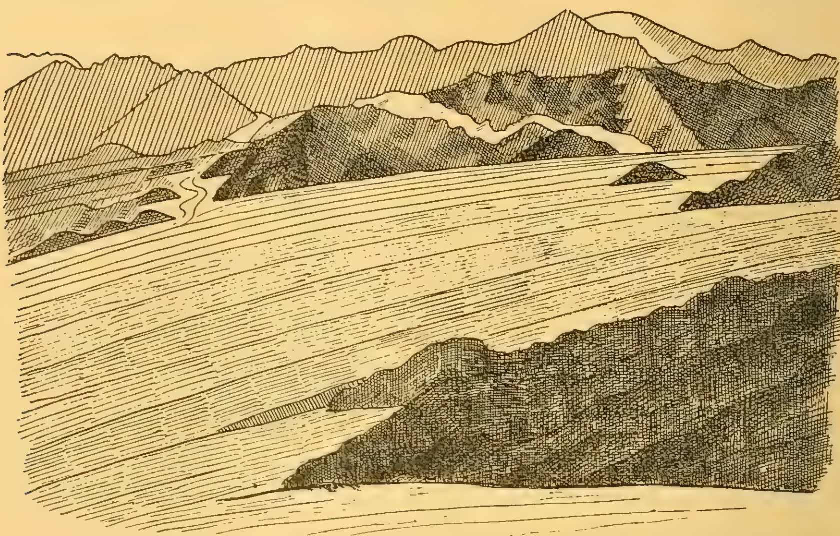

Fig 15. Lava and tuff accumulations (dark hills in the background) of probably tertiary age, seen from the eastern wall of the Tambillos valley. Looking north. The dômeshaped summit in the distance is the Cerro Cacho. The promontory in the foreground is of the old crystalline basement. The even slope is sheet flood gravels.

mass contains occasionally cavities. There are also smaller fragments of quartz and the rock may be classified as a quartziferous syenitic vitrophyre.

Intercalated between these lava masses lie tuff layers, generally of paler colour and well visible at a greater distance (cf. fig. 15). These layers dip all northward. Microscopically, the tuff contains abundantly grains of corroded quartz in an allotriomorphic mass of pigmented feldspar and small quartz grains, irregularly distributed. Another specimen of the tuffs shows a high degree

of pigmentation by ferric oxide dust, as may be confirmed microscopically. Between crossed nicols the slide is only dull transparent, or nearly black. This mass seems to contain feldspar as principal component. Also larger feldspar individuals occur with a tabular development showing a perthitic structure. Regarding the „parallel extinction" in cuts perpendicular to M the feldspar seems to be a potash one.

G) THE TERTIARY AND QUATERNARY GEOMORPHOLOGICAL DEVELOPMENT.

a) A FIRST TERTIARY OROGENETIC PHASE.

Folding tectonic in the Sierra de Umango area.

As has been shown several times by Keidel (1910, 1914) a. o. the Argentine-Chilean Cordillera with its great pile of mesozoic sediments and volcanics was affected by a first folding process during middle tertiary time, antecedent to a phase, when the present alpine relief was formed. The two phases of diastrophism have been distinguished one from another by way of morphological evidences.

While a strong tangential pressure from the west affected the andine geosyncline during the first phase, it may be assumed, that the „Foreland" to the east, that is, the western margin of the pampean sierras-area also came into the zone of the pressure influence. Studying the tertiary tectonics in the foreland, one really finds in many parts *folding phenomena,* caused by overthrusting from the west. The first informations on these movements were brought by W. Penck (1915) from Catamarca, where the sandstones to the west of the valley of Fiambalá are folded in part.[1] Later on Bodenbender (1916) has mentioned similar phenomena also from the Nevado de Famatina. In the Sierra de Umango area there are

[1] About the Famatina range (stretching northward to Catamarca) he says (page 649): „Junge, tertiäre Faltung charakterisiert die Famatinakette im Gegensatz zu den östlichen Gebirgszügen."

likewise folded sandstones, appearing here in the so called „intermontane zone". This zone is, as said, limited to the west and to the east by gliding planes, the western one dipping 45° W and showing a fault-overthrust to the east. The zone border is here overthrusted by the edge of the crystalline basement block of the Sierra de Umango ridge. All the sediments occurring in this zone,

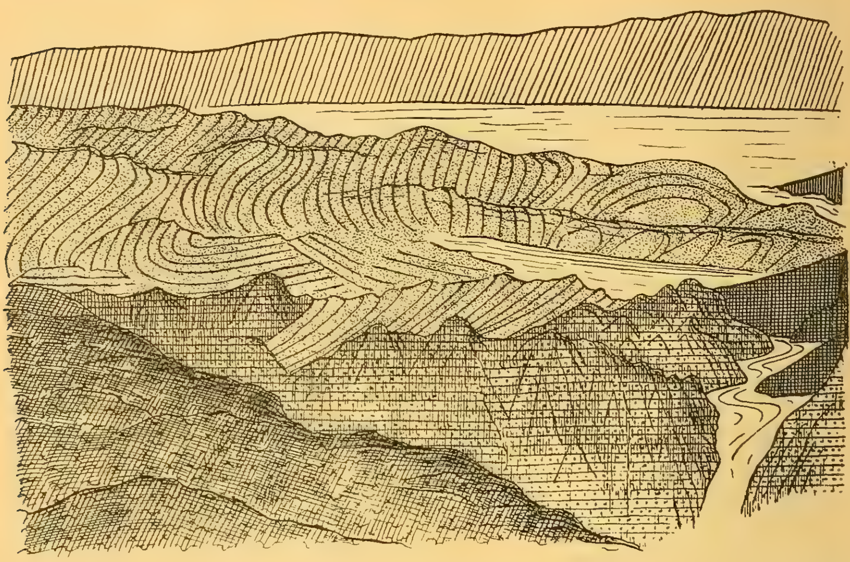

Fig. 16. Part of the „intermontane zone", to the NNE from the sector between the mountains. The picture will show the various bendings of the continental strata. These are overlaid by the horizontally lying young (tertiary) conglomerate (horisontally striated). In the foreground an edge of the mountain block of the Sierra de Umango. Looking east-northeast.

which runs between the mountain blocks of the Sierra de Umango ridge and the Cerro Potrero Viejo, are laid into strong folds, mostly upright ones. Also many faults do occur (see the figure 16). Outward the „intermontane" section no folds are visible, but monoclinal dipping and bending of the strata.

Close to the eastern border of the „intermontane zone", on the southern end of the Cerro Potrero viejo, there is a strongly folded complex of alternating lower Gondwana sandstone and slate. Here the folding may be regarded as an overthrust-phenomenon over

the basement. The contact with the latter is partly visible and shows a mylonitic mass, a mixture of sandstone and slate fragments and also a schist-breccia. A similar thrusting dislocation may be observed on a tilted basement (the overthrust plane rises towards the east) at the northern end of the „intermontane" section, at the northern head of the eastern mountain block, here called Cerro La Pampa (see the figure 19). The numerous fault lines, crossing the sandstone zone in longitudinal directions, have caused many irregularities in the succession and thickness of the strata.

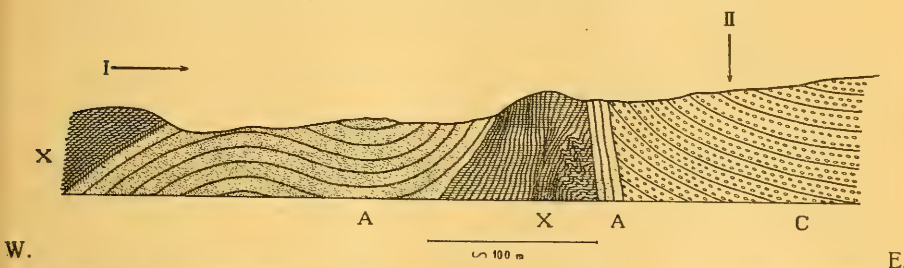

Fig. 17. A West — East profile through the tertiary dislocation zone (the Pirca zone) along the western foot of the Sierra de Umango ridge. Arrow I: di ection of the overthrust of old crystalline rocks over red sandstones, folded by this movement. Arrow II: a later downfaulting of the late tertiary conglomerate. A = red sandstone, X = old crystalline rocks, C = late tertiary conglomerate.

Another, but smaller zone containing folded sandstones occurs, as have been mentioned, at the western foot of the Sierra de Umango ridge and has been called the „Pirca zone". The red sandstone beds at Pirca are laid into relatively gentle folds, overthrust from the west by a faultblock of crystalline rocks, strongly crushed in the contact plane (see the profile 17). The amount of overthrust was, however, quite considerable, reminding of the „lambeaux de charriage" in the Alpes on a smaller scale. Blocks of old, crystalline rocks lie on the red sandstone beds (see the profile fig. 18). Also in some other parts of the Umango area we find signs of overthrusting and folding from the west.

From the morphological circumstances which will be more closely exposed, may also be seen, that these movements really belong to

an earlier phase than the below described vertical dislocations, by which the actual relief was formed.

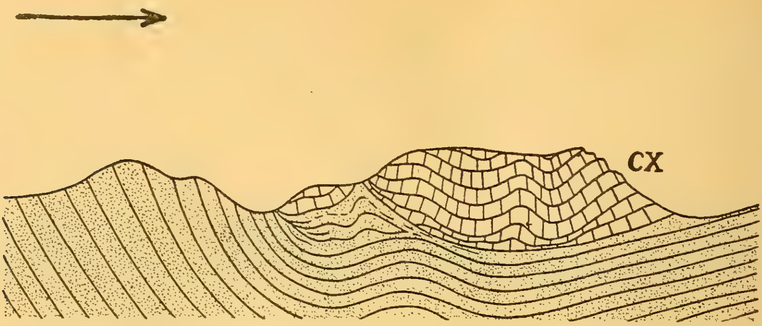

Fig. 18. Profil through the western border of the Pirca zone; Over-thrust of a crystalline block (CX) over a red sandstone. Length of the block ab. 300 m. The arrow indicates the direction of the overthrust.

In the Precordillera of Guandacol these tertiary movements have caused many complicated tectonical features in the permian structure, as is evident from the investigations by Rassmuss (1916).

The disturbances described above concern only the continental sediment-area series. But also the crystalline basement has been

Fig. 19. By overthrust folded sandstone beds resting on the surface of the crystalline Basement (the thrust plane). Northern end of the Cerro La Pampa and eastern border of the „intermontane zone". Looking south.

affected by the tangential pressure, not only in the immediate vicinity of the gliding planes, but also in the form of a regional kataclasis more closely described in a foregoing chapter. These dynamical deformations do not seem to extend eastward and outward the Umango area.

b) A LEVELLING PHASE SUBSEQUENT TO THE TERTIARY FOLDING PROCESS. FORMATION OF A MOUNTAIN GRAVEL CONGLOMERATE.

The above treated tertiary tangential movements have intensely affected not only the crystalline schists and the granites, but also the sediment cover of the continental series. It has also been stated, that these movements belong to an older epoch than the almost vertical dislocations now dissecting the Umango area in different directions and causing the actual alpine relief. A closer proof of this statement shall be made here and it will be clear, that an erosion phase lies between the two dislocation periods.

In the middle part of the Sierra de Umango ridge, on the very crest line, here at a somewhat lower level than farther southward there is a cap of a heavy conglomerate, extending downward on the slopes. The conglomerate rests partly on the crystalline basement, partly on the steeply inclined sandstone strata of the Pirca-„graben" and of the „intermontane" sandstone zone.

The whole appearance of the conglomerate, the high position and the situation in a relatively sunken area of the actual ridge and also its great thickness indicates, that it must have formed in former times a widespread gravel cover, extending over a more continuous surface, but was brought to the actual position and extension by a later uplift and subsequent erosion. This erosion is still working with great power, and in a relatively short time all the conglomerate here will be worn away.

This conglomerate corresponds doubtless to an erosion phase following immediately after the folding-diastrophism. Before a closer examination of this erosion and its results is made, it may be

convenient to charaterize in short terms the lithological habit of the conglomerate.

The quantity of the boulders in relation to that of the cement is very considerable. The size of the boulders is always large, and badly rounded forms dominate. They consist entirely of old crystalline rocks, gneisses, schists and granitic varieties of almost the

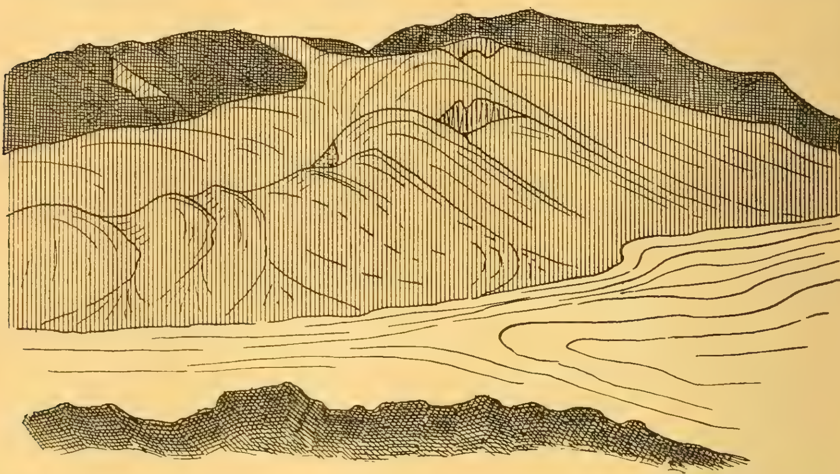

Fig. 20. Sunken erosion remnant of a young (tertiary) conglomerate, lying with great unconformity over a zone of strongly dislocated, continental strata. The vertically striated part of the picture signs conglomerate, the dark walls are basement crystalline rocks. The continental strata are buried. — A graben in the high ridge of the Sierra de Umango. Looking south toward the Cumbre de Umango.

same kind as in many parts of the Umango crystalline area. The conglomerate is clearly waterworn, and the cement seems to be a calcareous sand (it is now considerably endurated). Stratification is not conspicuous in all parts, but somewhere a distinct one can be observed. The sediment is jointed to vertical cliffs of great height, a test of a considerable cementation. Interstratifications of sandy layers have not been observed. The whole formation is evidently an ancient mountain shingle deposit, formed during conditions of steeper gradients. The material does not seem to be of a distant origin.

This conglomerate lies but in slightly tilted position. It ends

toward the west and east by fault planes, but to the south, where the ground is gradually rising, it seems to thin out. The downwarping of the conglomerate here took place very probably simultaneously with the other vertical dislocations of the area.

The conglomerate is worn away from every other part of the region. But how is it with the basal plane of this accumulation? This may still be seen in several parts, and especially, where the levelling process has gone through the crystalline basement.

Already in the introduction was mentioned, that all the high mountains in this part of the province generally have a flat topped summit, almost corresponding to the heights of the upland surface of the neighbouring Cordillera to the west. These summits might be the small remnants of a formerly levelled surface of wide extension. It depends probably on the late age of the uplift of the present mountains and partly also on the greater resistence of the old crystalline rock-ground, that the remnants are still preserved. The former surface was surely worked out later than the folding of the continental sandstones, judging from the centre of the area, where the mentioned conglomerate does occur. This may have been deposited on the same surface, whose remnants are preserved on the flat topped summits. It is evident from the character of the conglomerate, that this surface was not a „peneplain“ with a slow drainage. The general slope probably had quite a considerable gradient from a mountain region to the west, which was uplifted at same time as the the continental strata were folded. The great thickness of the conglomerate and the boulders always of old crystalline rocks show, that this erosion must have worked quite deeply into the basement ground. The detritic products of the continental sandstones, etc. have been carried further on and deposited on lower grounds. Some of the younger soft tertiary strata in the lowlands may be of that origin.

[1] Probably this phase of erosion already destroyed older peneplains and erosion surfaces, such as the sub-Gondwana and the subcretaceous, except in localities, where the overlying strata have recently been removed by erosion.

c) THE DEVELOPMENT OF THE ACTUAL RELIEF.

The network of the lines of vertical dislocations.

After the deposition of the above described coarse conglomerate, probably covering considerable areas, the ground of the area was affected by strong uplifting movements, causing, as known, the actual alpine relief of the whole Cordilleran chain and of all the pampean sierras. These movements went in the Umango area as everywhere else along vertical or steeply dipping slide or fault planes, running in different directions.

Along these lines of dislocation the cover of the continental sandstones sunk down with accompanying tilting of the strata and with formation of flexures or by a simple crosscutting of the layers, so that their edge lies directly against the crystalline fault wall in a more or less horisontal position. It is therefore quite simple to determine the position of the dislocation lines: these are represented by the limit between crystalline floor ground and clastic rocks, in the topography marked by a more or less abrupt slope. On the accompanying map of the Umango area the principal lines have been fixed.

According to the statements above it is evident, that all the lower areas really must be occupied by sunk parts of the continental sediments, while the greater elevations are composed of the crystalline ground. These elevations are but very exceptionally capped by the uplifted parts of the sediments, since almost all of them have been destroyed by erosion.

A short description of sunk parts of the sediment cover, that is, the tectonical valleys and lowlands, will follow in the next pages.

Description of the sunk (down faulted) areas.

The Vinchina valley.

As mentioned, the Sierra de Umango topographical complex is very markedly separated from the Famatina ridge to the east by the deep broad and long Vinchina valley running from the moun-

tains of the Catamarca province (in the north) southward with an increasing breadth and ending in the Pagancillo lowland. The bottom of this great valley consists of sandstones of the continental series, mostly of red colours, to the south, however, overlaid with younger, tertiary strata, attaining a great extension in the Pagancillo lowland. It is evident that these substrata of sandstones generally must be of no great thickness, because in the middle part of the valley, in the vicinity of Villa Castelli, a great number of smaller crystalline hills occurs, covering quite a considerable area (Cerro Asperecito, etc.) The walls of the valley almost expose the crystalline ground. North from the Sierra de Umango ridge the western wall is, however, a sandstone ridge, separating the valley from the Jaguel bolson. More to the south the same side is formed by the sandstone hills of the Cerro Punta Colorada. The eastern wall, the high slope of the Famatina mountain, shows in the foreground a series of smaller crystalline hills extending from Villa Castelli some leagues to the south.

The tectonical type of the valley is a longitudinal throw or „graben". There have been minor faults along the chief lines of dislocation, as is seen from the occurrence of several smaller faultblocks of longitudinal extension, now appearing as foothills. The strata of the Cerro Punta Colorada are tilted in direction of the valley and show a continuation into the bottom layers. The Cerro Punta Colorada is thence formed by a bending up of the substrata of the valley by the rising of the basement here in the form of a separated fault block. Or more exactly, here is a whole system of small blocks, as stated before.

The Pagancillo lowland.

The lowland forms an immediate continuation of the Vinchina valley. It is limited to the east by a southern prolongation of the great western flanc-fault of the Famatina mts, here cutting across an uplifted table of the continental sandstones and forming a bluff or

„*cuesta*“ facing west. This dislocation was mentioned by Bodenbender (1911). To the west the lowland is bordered by the upbent edges of the same strata, here forming the ridges of Lomas Coloradas (Cerro Colorado) and Cerro Bola. In the bottom of the lowland the strata seem to lie almost horisontally.

Simultaneously with the sinking down of the Pagancillo lowland many disturbances occurred between the Cerro Villa Union and the Cerro Bola, causing the marked downfold of the strata now separating the two mountains. The axis of this synclinale runs NE. But while the strata on the eastern side of the Cerro Bola dip to the east, a great bend of the strata may be observed when regarding the mountain from the northern side.

The Guandacol valley.

The most extensive lowland in these regions, the valley of Guandacol or of the Rio Bermejo with its continuation far to the south, is the dividing line between the Precordilleran chain and the Cerro Villa Union — Cerro Bola. I have studied only the eastern wall of the valley, as the western wall was mapped by Rassmuss. It is interesting to see, that the great fault line, which forms the eastern wall, is *younger* than the dislocations of the Cerro Villa Union on its southeastern and eastern sides. In the southern edge of the last named mountain the SE-ward tilted strata of the Gondwana series are vertically cut across to the west by the above named great fault line. The downfold between the Cerro Villa Union and the Cerro Bola is consequently older than the Guandacol valley.

The young fault line along the eastern wall of the Guandacol valley was already described by Bodenbender (1894). It is a very long one forming the western border of the Cerro Villa Union, the Cerro Bola, the Cerro Rajado and the Sierra del Valle Fertil more to the south [see the map by Bodenbender (1911)]. Toward the north the valley is rapidly getting narrower and the bottom rises.

The narrowing is due to an intervening ridge of sandstones, the Cerro San Antonio, running north (see the map!).

The tectonical valleys of Tambillos-Guandacolinos.

These valleys may be regarded as a tectonical continuation of the Guandacol valley to the NW, separated from it by the named sandstone ridge of Cerro San Antonio. The Precordilleran border still forms the western wall, here a more abrupt one. To the east rise the high slopes of the Umango mountains. On this side there are observed vertical gliding planes with tectonical striae. The valley of Tambillos is filled with sandstones of the continental series well exposed by the erosion. They are mostly dipping westward. The Guandacolinos valley more to the northwest lies higher than the Tambillos valley and thence the bottom sandstones here seem to have been worn away by erosion. Crystalline hills are therefore not unusual here. This last named valley cuts obliquely across the Umango-schist-structure. It ends where the Umango complex gains the Cordilleran border.

The Jaguel bolson.

It has already been stated, that the Umango structure is separated to the north from the similar structure in the Catamarca mountains by the depression of the Jaguel bolson, where the old rocks are covered with a mighty formation of sandstones and recent alluvions. The Jaguel bolson is a typical kettle-formed „graben", surrounded on all sides by mountain walls, except to the east, where a low sandstone ridge rises, which forms the northern continuation of „the intermontane sandstone zone". To the west and east the slopes of the walls consist of the continental sandstones, *dipping inward.* To the south there are no sandstones visible as flanc-cover, but the old Umango structure is here cut across, dissappearing rapidly beneath the young accumulations. The same peculiarities seem to be dominant also on the northern border of the bolson.

The sinking down of this bolson evolved before the high seated conglomerate in the Sierra de Umango ridge was deposited, because this conglomerate lies unconformably over the tilted strata of the eastern border of the bolson (or exactly, over their southern continuation). The strata were naturally tilted up together with the formation of the bolson.

The above named conglomerate, situated on the ridge of the Sierra de Umango, is, as has been stated, preserved in a smaller downfaulted area, which seems to be of a later origin than the valley-forming dislocations.

The nearly smooth ground, which forms a kind of highland plain between the Cerro Cacho and the Sierra de Umango ridge, may be considered as a relatively sunken part of the older tertiary levelled surface. No remnants of the sediment cover are preserved in this area, and that depends naturally on the relatively high position of the plain, which slopes rapidly down to the north and south.

The crystalline horst-blocks of the Umango area have in many respects the same character as the pampean sierras, formed as they are by similar dislocations. But the conspicuous phenomenon of *tilted blocks,* as generally developed in the last named sierras,[1] is hardly seen in the Umango area. The Famatina mountain blocks seem, however, to follow this rule, according to which the western borders of the mountains have been more uplifted. Also the Cerro Villa Union has a tendency to a similar behaviour, although worse developed, while an upland plain is but little preserved. The western slope is, however, higher and steeper than the eastern. Tilting does not occur in the principal part of the Umango mountains. *They form a part of the Cordilleran late tertiary uplift zone,* and in this respect the area lies aside from the pampean sierras-region, while the Nevado de Famatina may already belong to the last named.

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[1] Juan Rassmuss: Rasgos geológicos generales de las sierras pampeanas. (1916).

(d) THE POSTPLIOCENE EROSION AND ACCUMULATION.

General conditions of erosion.

With the great late tertiary uplift-movements a new geogiaphical cycle began in the andean regions. From the present morphological forms in the Umango area may be concluded, that this cycle must still be in a little advanced stage. *The elevations are to their extension still determined by the fault lines.* This statement is applicable even to the most intensely faulted grounds, where every hill is a little horst. The youthful stage of the erosion is also manifested by the deep and narrow profiles of the valleys, the rapidly descending erosion-curves on the slopes and also by the still preserved relics of upland plains.

The general topographical situation of the Sierra de Umango area in the interior part of the Republic may be characterized as follows: The area lies aside from the pampean plain and in a high position with respect to the local baselevel. The mountains form, as said, really only a part of the Cordilleran bulk, except some more isolated parts (Cerro Villa Union, a. o.).

Examining indeed the *erosion*-forms of the Umango area, belonging no doubt to the physiographical province of the pampean sierras with their very rough and dissected surface, one reveals the dependency of the erosion in the last named sierras as well as in the Umango mountains upon the possibility to attack the more or less isolated blocks from all sides, and upon the existing great level differences. Westward again in the Cordillera the vast highland-area misses deep dissected valleys, and thence the linear erosion has but slightly progressed. The Cordilleran upland surface is still preserved over wide areas. To these belongs the part lying immediately to the west off the Umango area and contrasting with the later in a very conspicuous manner.

The principal outlet-course for the whole drainage in the Umango area, leading down to the pampean plain, is represented by the

Rio Bermejo, which follows in its upper part the Guandacol valley and runs then southward along the western border of the Sierra de la Huerta between this mountain and the Sierra Pié de Palo. Further to the south the river joins the Rio Desagüadero. Here the plain lies 457 m over the sea. The last named river flows then further southward, ending in a wide depression without outflow, in the Gobernación de La Pampa.

At present time the Sierra de Umango has consequently no drainage to the sea, in this respect being of the same nature as the whole interior part of the Republic between Tucumán in the north and the headwaters of the Rio Colorado in the south.

The more distant bases of erosion are, however, of no importance for the development of the land-sculpture in the Umango area. Here may only be considered the local bases, each of these being in arid conditions and of great influence upon the forming of the sculpture.

The lowermost local baselevel of the Umango area is represented by the bottom of the Guandacol valley. Other somewhat higher levels are the Pagancillo and the Jaguel bolson floors. The absolute heights of the different plains are as follows:

Valley of Guandacol................	910—950 m.
Pagancillo lowland	1190 m.
Valley of Vinchina	1260—1400 m.
Jaguel bolson	1844 m.
Valley of Tambillos	2225 m.

At present the erosion is controlled by an arid climate,[1] which seems to have prevailed during the whole quaternary and recent periods. The development of the landsculpture in desert regions has been explained by W. M. Davis.[2] According to W. M. Davis, the enumerated local erosion bases cause a corresponding

[1] G. Davis; El clima de la República Argentina. Buenos Aires 1909. Page 73.
[2] W. M. Davis: The geographical cycle in an arid climate. The Journal of Geology. July-Aug. 1915.

number of independent centripetal drainage systems with heavy accumulations at the base. In the Umango area the different base-levels communicate by small streams cutting across the dividing ridges, but their scarcity of water prohibites any sudden levelling between the different bases.

According to a paper recently issued by Keidel[1] the mountains in the northwestern parts of the Argentine Republic got their principal relief already in preglacial times. In the formerly glaciated areas, it may be observed *that the mantle of glacial deposits covers all the main forms.* The piedmont-stream-deposits are consequently chiefly of preglacial age. The preglacial climate was dry as the present.

In the Umango area glacial deposits are completely lacking and cannot furnish any information in this respect. It is, however, quite certain, that the principal drainage lines here, viz the main erosion lines are of old age. This is evident on regarding the giant gravel cones radiating from the mouth of every such valley. The cones are generally uplifted and dissected by younger erosion (cp. fig. 23).

1) A first erosion phase.

The late tertiary *tectonical* relief was in its initial stage probably built up as follows: all the great blocks were composed of the basement rocks and flanked by the continental mantle of sediments, which generally dips outward from the block cores. At an earlier time this mantle probably covered also the very summit of the blocks. The young tertiary conglomerate capped probably all the summits.

The present strong relief was brought out chiefly by the carving out of the hard crystalline blocks as result of the destruction of the continental strata in the depressions.

[1] Hans Keidel: Ueber den Anteil der quartären Klimaschwankungen an der Gestaltung der Gebirgsoberfläche in dem Trockengebiete der mittleren und nördlichen argentinischen Anden. Compte Rendu. XII. Session. Congr. Géol. Intern. Canada 1913. Ottawa 1914. Pages 757—769.

During the first phase of erosion, a mighty cover of coarse conglomerate (the late tertiary) was really destroyed to an extensive degree which is indicated here and there by visible remnants of quaternary shingle, composed of the same boulders as the young tertiary conglomerate, thus representing a re-deposition of tertiary material. These quaternary shingle deposits were afterward destroyed by subrecent erosion to a considerable degree. They occur at localities, where there are signs of dislocation of later date.

Such a remnant of quaternary shingle, afterward dislocated, is visible at the southern end of the Cerro Potrero Viejo, at the eastern border of the „intermontane sandstone zone". A recent river gorge

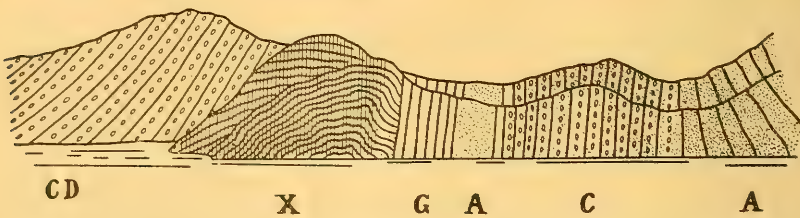


Fig. 21. An E—W profile from the vicinity of Altillo, E border of the „intermontane zone", showing tertiary and diluvial dislocations. *CD* = diluvial conglomerate. *X* = micaschist. *G* = Gondwana sandstone. *A* = red sandstone. *C* = tertiary conglomerate. *A* = red sandstone (cretaceous?)

is carved out through the gravel and also through the older strata to the west, against which the gravel has been dislocated (see the profile, fig. 21). The gravel being distinctly bedded with much sandy material has been laid into a flexure. Upward the profile is limited by a gentle eastward dipping surface of a young sheetflood. The quaternary dislocation had here a direction parallel to the tertiary of the intermontane zone, as the profile figure shows.

Another remnant of diluvial gravels, to some higher degree hardened to conglomerate, was found in the valley bottom of the Rio La Troja, at the western foot of the Cerro Villa Union. The gravels form here a mighty vertical wall facing the eastern margin of the river, but slope gently to the east, toward the recent mountain fans. In the river cuts the gravel shows almost horizontal layers.

The lateral erosion of the Rio La Troya has probably extensively destroyed this gravel formation and the levelled part has been completely covered with modern alluvions. At Carrizal the gravel is limited by a fault.

It is very probable, that such a gravel also occurs in the Jaguel bolson (in the north), but the recent alluvial cover does not permit any observations, except in one place, in the immediate vicinity of the settlement of Jaguel, where there rise some low hills over the plain, which are composed of similar gravels, but slightly hardened and not much dislocated. One may assume, that a great part of the filling masses of the bolson consists of the same gravels, as the bolson was re-deepened also in posttertiary time.

After the destruction of the young tertiary conglomerate cover the erosion pursued in the continental sandstones lying on the basement block sides. This denudation process appeared in a successive formation of sheet flood terraces, on lower and lower levels.

2) Sheet Flood erosion.

This characteristic kind of mountain degradation was more closely explained by Mc Gee.[1] The author states with regard to the general conditions of sheet flooding as follows: „The first requisite for typical sheet flooding is a precipitation so rapid, as to exceed immediate absorption of the dry earth and immediate evaporation in the dry air. An attendant condition is, that the precipitation shall be rapid. A third condition is, that the soil shall be readily pervious only in limited degree, or to limited depths. And this condition is met with on the lightly veneered baselevels adjacent to the mountains, where the mantle only is porous and the underrocks sound and hard; it is not met with in the deeper central portions of the valleys, where the permeable sands are of considerable depth.“ The gradient of the slope must be about 300 feet

[1] Mc Gee: Sheet flood erosion. Bulletin of the Geological Society of America Vol. VIII. 1897. Pages 87—112.

per mile. Further the quoted author states: „The sheetflood is characterized by a tendency to spread widely in relatively narrow sheets (of gravel loaded water). In a general way, streams prevail in humid regions, sheet floods in arid regions, though streams occur locally also in arid lands, while it seems probable, that sheet floods occur *under certain conditions* in nearly all lands, howsoever humid."

Almost all the above enumerated conditions prevail in the Sierra de Umango area, and the sheet flood phenomenon has therefore

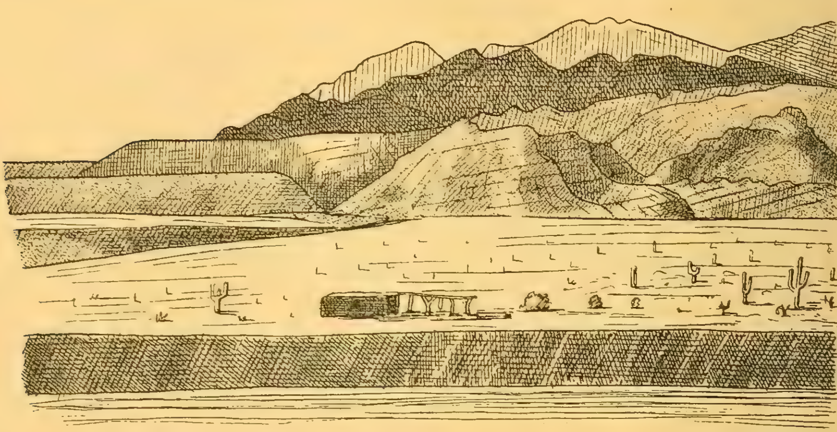


Fig. 22. High destructive, diluvial (?) terraces, carved out in red sandstones. Southeastern side of the Nevado de Famatina at Puerto Alegre. Looking north. The high ridges in the background are granite. The ranch lies on a subrecent sheetflood surface.

here a very typical development. Rapid precipitations occur in summertime in the form of the so called *„crecientes"*. The soil is in the shallowest underground already quite hard, consisting of the endurated continental sandstones.

The same conditions for sheet flooding have prevailed down to quite recent times during the successive degradation of the sandstone mantle of the crystalline block sides. The whole process was merely a formation of lower and lower, gentle sloping terrace planes, a kind of *destructive terraces,* carved out in the sandstone mass.

Very few older sheet flood terraces (situated on higher levels) are yet visible. In the „intermontane zone" there are in some parts

along the eastern slope of the Sierra de Umango ridge a few remnants of gravel covered plains more than a hundred meters over the valley bottoms (Quebrada Espinal). — To the east of Villa Union, near to the extreme foot of the Nevado de Famatina there are also remnants of older plains appearing in the form of well marked terraces (Puerto Alegre). Some lower terraces farther out in the lowland are of considerable extensions. They all slope westward from the Nevado. In former times they have probably extended over the greater part of the Pagancillo lowland. The Lomas de Villa Union are but the last withnesses of these plains. Every hill here has a flat summit covered with a gravel sheet (old sheet flood plain).

The best preserved sheet flood cones are, of course, those of younger date (later quaternary?). They, indeed, form almost all lower slopes of the existing mountains. The best developed ones occur on the eastern slope of the Cerro Potrero Viejo (toward the open Vinchina valley). Also the cones on the western side of the Cerro Villa Union (the Guandacol valley) are of wide extension. Giant cones have developed also along the western margin of the Nevado de Famatina.

Recent sheet flood cones seem not to be developed, because the last erosion phase, as will be stated below, has only worked by linear way, cutting through the cones and forming canyonlike gorges. The main cones correspond to the main valleys, *and the main features of the sculpture seem to have been formed during the last phase of sheet flooding.*

3) A later (recent) erosion phase. Linear cutting. River terraces.

On studying the great sheet flood cones and their corresponding valleys one finds, that these forms have been to a high degree modified by a erosion, caused by an subrecent *uplift* of the mountains (or by a relative sinking of the valley floors.) This later phase

of erosion was thence rejuvenating by way of *linear cutting* in the sheet flood planes and by a deepening of the corresponding valley profiles. Some of the cones are to such a degree dissected by the young erosion, as to be changed into a „bad land" sculpture (northern end of the Cerro La Pampa). Many curious hilly forms have been shaped where the sheet flood gravel has endurated to a hard bed, mostly like mesetas and separated by steep canyons. The Lomas of Villa Union, as mentioned, remnants of a great cone-

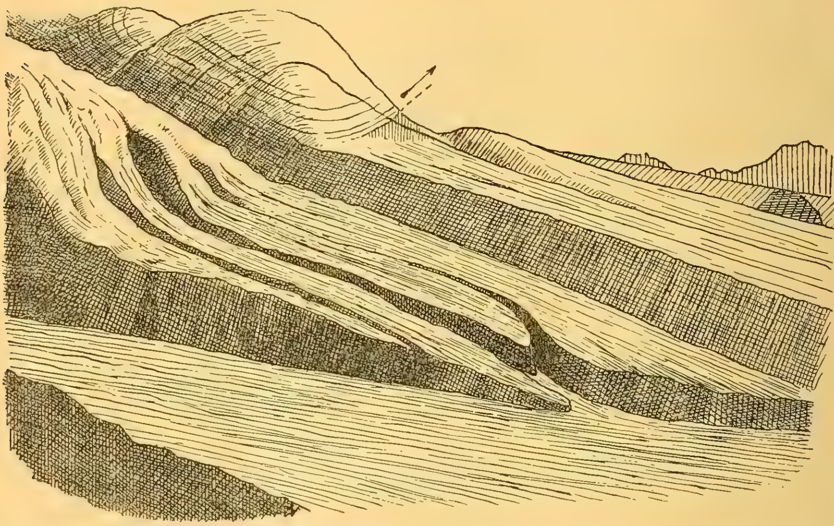


Fig. 23. A wiew of the eastern side of the Sierra de Umango ridge, looking north, along the „intermontane zone". The picure demonsrates the formation of piedmont (gravel covered slopes) cut across by young erosion. The arrow indicates the overthrust plane between the mountain block and the sediment zone. The stream bed of the Quebrada Cordobés in the foreground.

surface extending from the Nevado toward the Pagancillo lowland, have all a table shape, due to the hardened gravel sheet very resistant to the erosion.

The young erosion has also worked laterally in more advanced stages and thereby reduced the cones into flattopped ridges radiating from the apex of the former cone (see the terraces NE from the Villa Union.)

In the valley bottoms, except in the Guandacol valley, there are

in many parts well developed *river terraces* of quite recent age. These terraces are not of an accumulative, but of a destructive kind, carved out in the sandstone terranes, the substratum of the lowlands.

The most perfect terraces are met with along the lower course of Rio Bermejo, between the Villa Union and the Paso de Lamar, that is, in the western part of the Pagancillo lowland. Excellent terraces occur also in the named *Paso*. It is obvious, that all these terraces have been formed by a successive throughcutting of the sandstone ridge of Paso de Lamar, due to a gradual tectonical sinking of the Guandacol valley floor. It may also be assumed, that the breaking off of the barrier of the Paso de Lamar has adjusted the whole drainage of the Pagancillo lowland and the connecting Vinchina valley during the last erosion phase. The Lomas of the Villa Union have thence been carved out by this adjustment, as later on the very river terraces along the edge of the flood plain of the Rio Bermejo.

Upward from the Villa Union no more terraces are visible except in its near vicinity to the northeast. The upper part of the Vinchina valley is, as far as I have seen, only an even sandy floor (so called „*medano*"), and the sheet flood cones on both sides are not dissected. This part of the valley lies yet aside from the influence of the Paso-de-Lamar-adjustment.

In the Bolson of Jaguel the results of the latest erosion are developed only to a very small degree. Almost the whole basin is an flat accumulation plain. The Jaguel river, crossing the plain from NW, has no marked valley, except where it approaches the sandstone ridge to the east, the outlet-canyon down to the Vinchina valley. Here a backward erosion carves out the alluvial accumulations of the plain, and some terraces have been formed. The erosion tends, however, to extend its work over the whole plain until it would be paralyzed by alluvial depositions from the surrounding slopes.

The large tectonical depression of Zapallar — Nacimientos —

Tambillos, separated from the broader Guandacol valley by the sandstone ridge of the Cerros de San Antonio (the southern prolongation of the „intermontane sandstone zone"), has a very broken bottom, due to a young erosion of old valley floors. This rejuvenation originated from the throughcutting by the Rio La Troya of the named sandstone ridge. Standing on the slope of the mountain, which rises to the east of the Tambillos depression, and looking westward, one obtains an excellent view of the now intricately dissected old valley floor, once flattened over the variegated series of filling sandstones. The erosion is a subsequent one, following the complicated fault tectonics of the strata. The numerous hills carved out in these sandstones show still on their flat-topped summits the remnants of the mentioned ancient valley floor. Upward the slopes the old surface passes into less dissected sheet flood cones.

The Rio La Troya (which is dry during the greater part of the year) „upstream" from the Tambillos depression leeds to the Guandacolinos depression, which separates the Cerro Cacho complex from the near situated Cordilleran border. Here, as in the upper part of the Vinchina valley, are no signs of young terrace cuts. The valley floor is a flat sandy „*medano*".

4) Differences of the detailed sculpture in the crystalline rock-ground and in the terranes of the continental sediments.

Results of the last erosion phase are visible also in the minute surface forms of the mountain slopes, which dissect the ground in a manner possible only in desert-regions. In the crystalline rock ground such an asperous surface has been formed as to make the forthcoming almost impossible. The only usable trails follow the gravel filled bottoms of the larger *quebradas*. The numberless sharp ridges have been called in Spanish „*cuchillas*" (= choppers). Above

these slopes nearer to the lofty summits of the mountains the „*cuchilla*"-sculpture changes into quite a broadlined one (fig. 24). The very summits are often almost plain. This feature is naturally due to the youthful stage of the erosion, according to which the high parts still remain unaffected by it.

The „*cuchilla*"-sculpture of the crystalline rock ground stands in a marked contrast to the detail-forms, developed in the continental sandstone terranes on the lower hills at the foot of the great blocks and also on the cores of the sheet flood cones, when these have been dissected

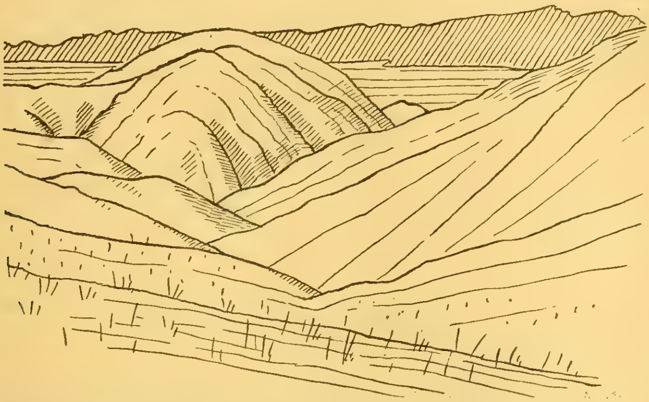
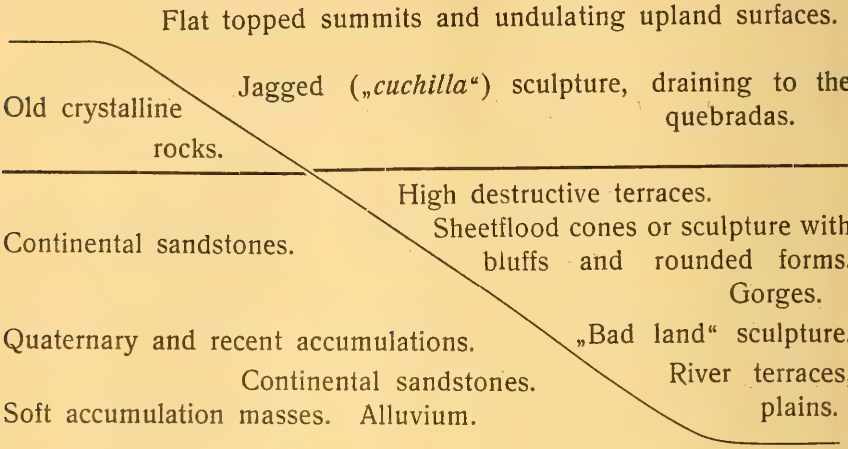


Fig. 24. Highland topography near the crest of the Sierra de Umango ridge. View to the east with the Nevado de Famatina in the distance. (Height of observation point about 3000 m.)

to a higher degree. The sandstone-forms are generally more rounded and broader than is the case with those in the crystalline ground. The shape of the ridges of the sandstones depends naturally on the dip of the strata. When they lie horizontally or dip gently, the table- or „*meseta*"-forms dominate. When they stand vertically the result is a wild labyrinth of steep gorges. Such a country is mostly impossible to traverse. Characteristical of the sandstone terranes are the numerous bluffs or vertical walls, sometimes several hundred meters in height. They may partly be the result of faults, but often they are but erosion forms. The bluffs occur especially in places, where the strata dip under angles of about 30°.

The strata of the quaternary and recent accumulations in the valleys being much softer are sometimes dissected into „bad land"-like forms, but generally they are not affected by erosion.

At last may be communicated a scheme of the principal sculpture-zones as they depend on level and nature of the mother-rock.



H) MINERAL OCCURRENCES.

Selenide bearing veins.

In comparison with the Nevado de Famatina and its famous richness of metalliferous minerals, well known also in the Anglo-American mining world, the neighbouring mountains to the west, the Sierra de Umango region, have but insignificant occurrences of exploitable minerals to offer. The most worked ones are the *silver-selenide bearing veins in the Cerro Cacho complex.* The first discovery of these was made by the mining engineer E. Hünicken, engaged in the Famatina Copper Company. Later on professor L. Brackebusch collected several specimens of these selenides during his expeditions in the years 1875—1888. The specimens of Brackebusch were then more closely examined in Germany.[1]

[1] Otto: Eukairit aus Argentinien. Berichte der deutschen Chemischen Gesellschaft. Jahrgang XXIII. 1890.

F. Klockmann: Ueber einige seltene argentinische Mineralien. Zeitschr. für Krystallographie. Band XIX. N:o 3. Leipzig 1891.

The chief selenide veins lie on the eastern slope of the Cerro Cacho, some leagues to the west of the Puesto Umango. The veins have been exploited some ten years ago by an Argentine mining prospector. The claims are still visible and well accessible, but all valuable parts of the mineral mass have been quarried. Without operating with dynamite it seems impossible to obtain any good specimens of the minerals. The selenides, *eukairite* and *umangite,* have been exploited for their high value in silver and copper. The ore was brought on muleback over the Sierra de Umango ridge and the Paso de Tocino over the Sierra de Famatina down to the town of Chilecito along asperous and even dangerous trails. The mines lie very high, about 3000 m and the icecold storm from the Cordillera sweeps nearly the year round over these heights.

The selenide minerals mentioned occur in thin fissure veins transversally cutting across the crystalline schists. These last named consist principally of limestone and amphibolite, contorted in many ways. The gangue mass is for the most part calcite and quartz. The metalliferous minerals occur as scattered grains or irregularily formed dense masses. According to Klockmann (l. c.) these minerals are, as already stated, eukairite and umangite. The former mineral has the composition AgCuSe, the later Cu_3Se_2. The eukairite is as specimen known already many years ago, principally from Småland, Sweden.[1] The Umango-eukairite was, as said, first found and examined by Hünicken. The umangite was, however, fixed by this explorer as bornite, but the true nature was then stated by Klockmann. The chemical composition of the two minerals is according to him as follows:

Eukairite:		*Umangite:*	
Ag	43 %	Cu	54 %
Cu	25 „	Se	45 „
Se	32 „	Ag	traces.

[1] A. E. Nordenskiöld: Öfversigt af Kongliga Vetenskapsakademiens Handlingar. Stockholm 1886.

Among the mineralogical characteristics of the two species may be mentioned, that the eukairite has a lead-white, granular habit with a brilliant lustre. The umangite shows in fresh fractures a reddish, dark colour and a high lustre. The habit is massive. Crystals of both minerals are unknown.

Other minerals associated with these are bornite and of secondary products principally malachite.

The veins have no visible relations to eruptives. They are considerably younger than the granites.

In the Umango area there are also some other occurrences of selenides, but of less importance. On the trail between the Puesto Umango and Tambillos there lies in a very broken ground a small mine called „la Millionaria". The chief rock here is a mica schist and the veins are as in the former case transversal. Malachite alteration products are also here very abundant.

In the Quebrada Agua de los Caballos situated in the eastern part of the Cerro Potrero Viejo another transversal vein cut through a gneissic rock. It contains abundantly hematite, gathered along the salbands of the vein. This occurrence was recently exploited (by a French prospector, 1914 gone off to the war).

Bodenbender (1911) mentions the occurrence of umangite- and clausthalite(PbSe)-bearing veins with a calcite gangue mass, cutting through the Famatina granite in the vicinity of the Piedra Pintada in the Sierra de Sañogasta. Outside the Umango area there are selenide bearing veins to the north in the province of Catamarca, where umangite has been found in the mountains to the west of Tinogasta. No further facts are known about the appearance of the veins here.[1]

Other selenide occurrences in the Argentine Republic are met with in the province of Mendoza, in the Cerro Cacheuta mining camp.

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[1] G. Bodenbender: Communicaciones mineras & mineralógicas. VIII. Criaderos de seleniuros de cobre etc. Boletín de la Academia Nacional de Ciencias en Cordoba. Tomo XVII. Cordoba 1903.

Since the discovery by Domeyko[1] a large series of papers[2] has already been published on these mineral findings. The veins set up in a porphyritic rock, which according to a verbal communication by dr Stappenbeck is of lower Gondwana age. The porphyrite sheet is crossed by numerous eruptive veins of young date, and these veins may be supposed to stand in genetic connection with the selenide occurrences. The selenide minerals here have a very varying composition and all the specimens have different names (see Domeyko, l. c.).

It seems probable, that the Sierra de Umango and the other occurrences of selenide minerals belong to the andine volcanic phase during which all the famous ores of the Cordillera and the Nevado de Famatina were formed. The straight cutting through of the Umango veins is also indicative of a very young age.

Occurrences of nickel ores.

Mineral occurrences of economic value, except the described selenide veins, have been found north of the Umango mountains, but in the same geological structure, where it reappears at the northern border of the alluvial plain of the Jaguel bolson. According to Brackebusch[3] there lies near to Potrero Grande a mine called „Solitaria“ and containing *niccolite* ($NiAs$) with 44 % Ni, the only finding of this mineral in the Argentine. *Annabergite* $[(AsO_4)_2Ni_3 + 8H_2O]$ has been encountered also. The veins here cross an amphibolite, associated with quartzitic and gneissic rocks. The mine was exploited during 1845 by two Germans, the Erdmann brothers. But the many political complications at that time in Argentine made it impossible for the miners to carry on their work.

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[1] A. Domeyko: Anales de la Universidad Nacional de Santiago de Chile. Tomo XXIX. 1876. Pages 62—68.

[2] See Stelzner (1876—85). Page 219.

[3] Ludw. Brackebusch: Die Bergwerkverhältnisse der argentinischen Republik. Zeitschr. für Berg-, Hütten- und Salinenwesen im Preussischen Staate. Bd. *41*. 1893.

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Explanatory note to the maps.

The topographical map was worked out during the wintermonths 1915 by the topographer of the Direction of Mines, Buenos Aires, mr Jorge Schultz contemporarily with my own field works. The original field sheets in greater scale were reduced to the scale 1 : 100,000 and connected to form a map of the whole Sierra de Umango area, except the western and northern parts of the Cerro Cacho complex, which remained unmapped. The present map shows also nothing of the mountains more to the west, i. e. the very border of the Cordillera, which the Sierra de Umango complex joins (Pampa de Leoncito and surroundings). Neither the western side of the Guandacol valley — the Precordillera Riojana — nor the eastern wall of the Vinchina valley — the Nevado de Famatina — are shown on the map. These mountains have, however, been mapped in other connections. To get a better orientation of the main topographic features in this part of the Republic a map of smaller scale should be used. The best existing is the hypsometric map of Ludw. Brackebusch (1893).

The geological map reproduced on the cover-sheet was prepared after the field work were finished and as soon as the topographical sheet was to the writers disposal. Thence only the main geological features were fixed, partly because the scale of the map is reduced to a considerable degree. I believe, however, that the quite numerous figures in the texte may be a kind of supplement to the geological picture of the area in question.

PLATE I.

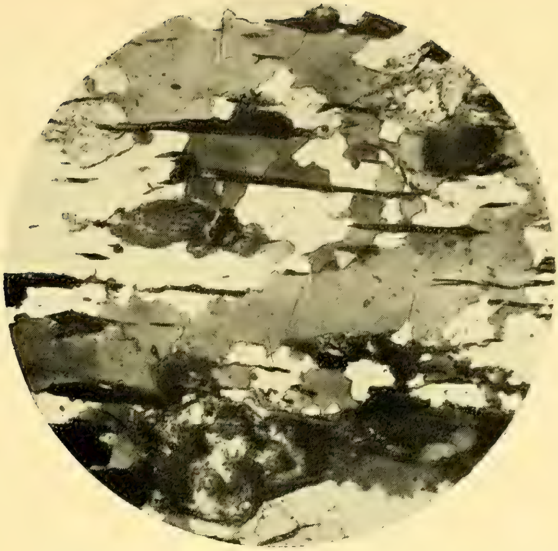


Fig. 1. A recrystallized mica — quartz schist. The dark, parallel stripes are biotite, the large grains quartz. Nic. +. Magn. 28 X. Cerro Potrero Viejo. Quebrada Agua de los Caballos.

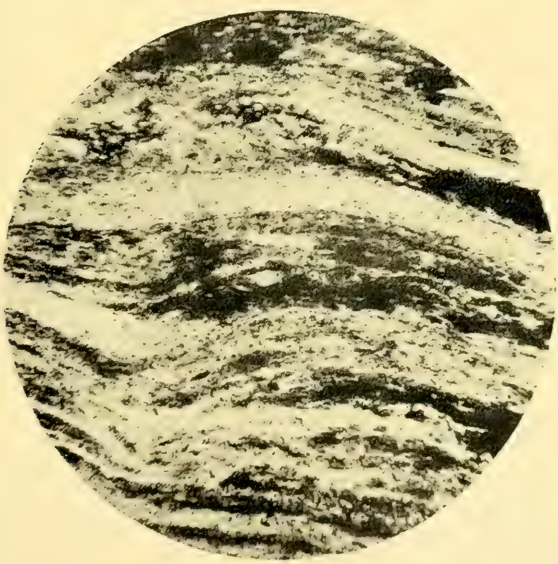


Fig. 2. Sericitic, microfolded ferriferous schist. Nic. +. Magn. 20 X. Sierra de Umango ridge, eastern side. Quebrada Salto (N from Casa Piedra).

Fig. 1. Famatina granite (aplitic type) of primary habit. The pale individuals are quartz, the darker perthitic potash feldspar. Nic. +. Magn. 20 ×. Sierra de Sañogasta. On the road Puerto Alegre—Sañogasta.

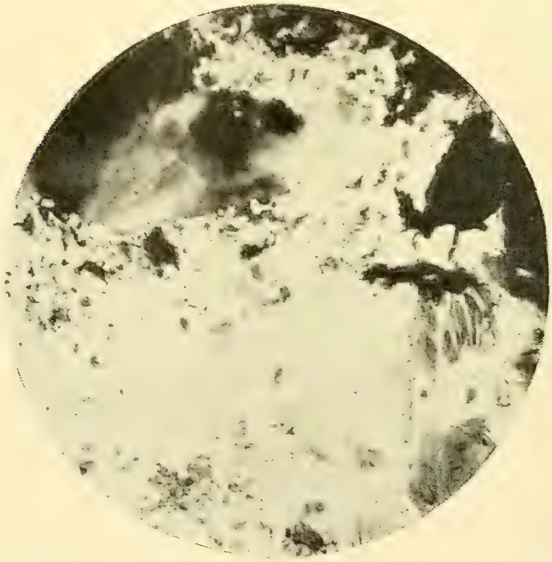


Fig. 2. Famatina granite, crushed. Nic. +. Magn. 20 ×. Sierra de Sañogasta. On the road Puerto Alegre—Sañogasta.

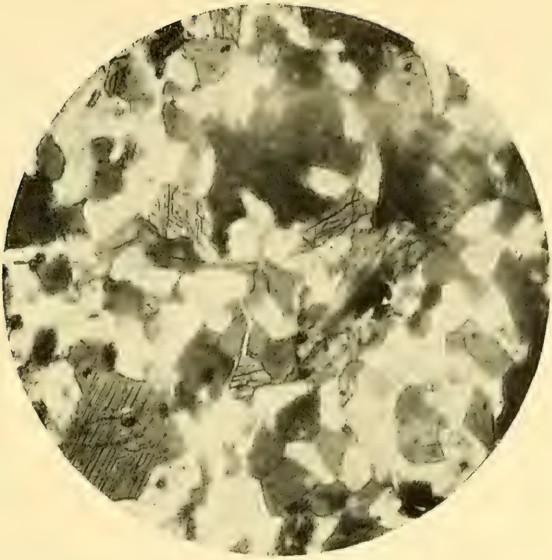


Fig. 1. Amphibolite of granoblastic, recrystallized structure. From a breccia fragment in granite. Nic. //. Magn. 88 X. Cerro La Vatea, opposite Villa Castelli.

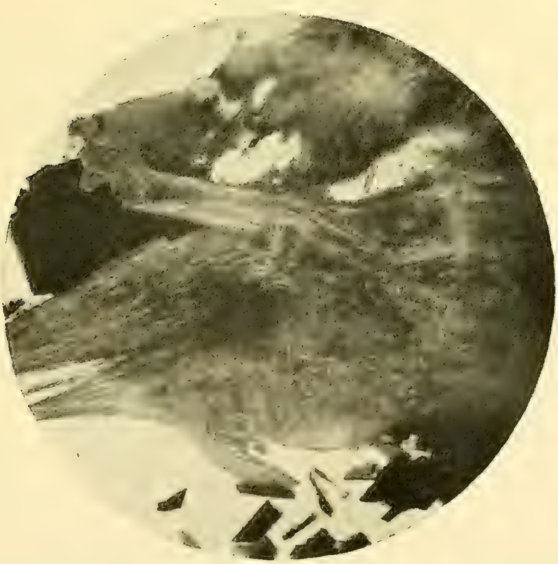


Fig. 2. Biotite transformed to fibrolite (sillimanite). Syntectic rock, surrounded by granite. Nic. +. Magn. 88 X. Cerro La Vatea.

PLATE IV.

Fig. 1. Amphibolite schist, to some degree metamorphosed by the white granite. The amphibole shows a beginning alteration to biotite, due to the acidification of the rock. The specimen was taken from a transition band between amphibolite and granite. The pale component is plagioclase and also quartz, the darker are amphibole and biotite. Nic. ⫽. Magn. 20 X. Quebrada Agua de los Caballos, Cerro Potrero Viejo.

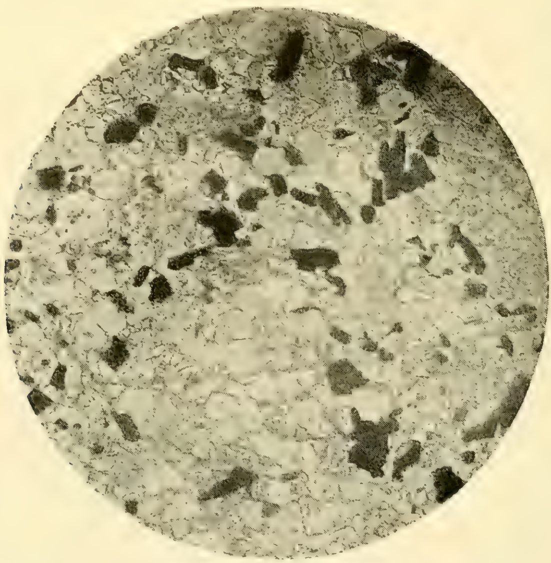


Fig. 2. Dark quartzite rock from an inclusion in young granite. Pavement hornfels structure. The black spots are biotite. Nic. ⫽. Magn. 120 X. Steep rock hill rising from the valley floor to the west from Nacimientos.

Fig. 1. A dynamic flow structure developed in a white aplitic granite, which forms a concordant vein in a mica schist. Nic. $\parallel$. Magn. 20 X. Western foot of the Cerro Villa Union, Carrizal.

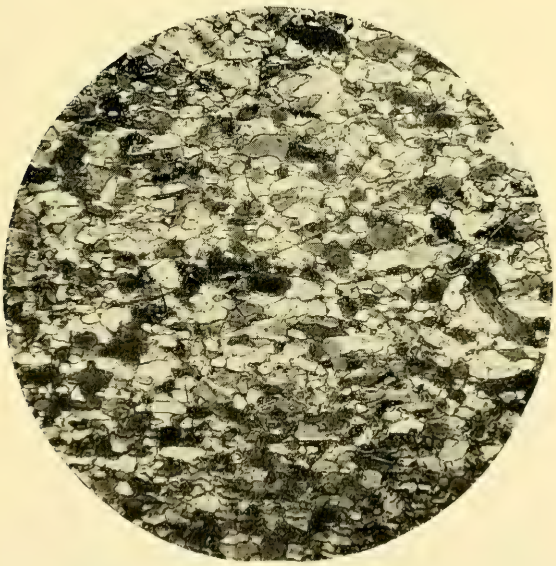
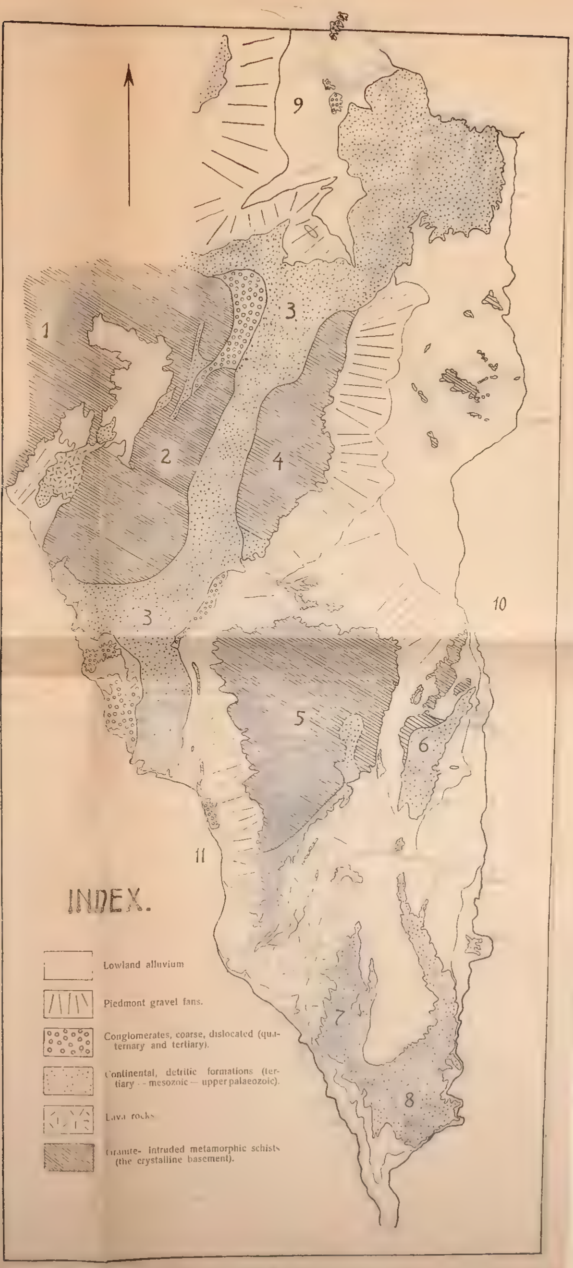


Fig. 2. Red aplite granite, completely granulated. Nic. $\parallel$. Magn. 28 X. The western foot of the high ridge of the Sierra de Umango at Arroyo Gaucho.

The main geological features of the

SIERRA DE UMANGO AREA

fixed by *H. Hausen.*



1. Cerro Cacho. — 2. The Sierra de Umango ridge. — 3. The „Intermontane zone". — 4. Cerro Potrero Viejo (Cerro La Pampa). — 5. Cerro Villa Union. — 6. Punta Colorada. — 7. Cerro Bola. — 8. Cerro Colorado. — 9. The Jaguel bolson. — 10. The [illegible] valley. — 11. The Guandacol valley.

THE SIERRA DE UMANGO AREA.

Mapped in the year 1915 by the Topographer of the Direction of Mines, Buenos Aires, Mr *Jorge Schultz*.

Scale of the original map 1:100,000. Scale of the present copy 1:400,000.

ACTA ACADEMIAE ABOENSIS
MATHEMATICA ET PHYSICA I:5

DIE LICHTEMISSION UNTER DER WIRKUNG MOLELEKTRISCHER KRÄFTE AN DER OBERFLÄCHE VON KRISTALLEN

VON
Dr. BRUNO SAXÉN
LEKTOR DER PHYSIK A. D. AKADEMIE ÅBO (FINLAND).

ÅBO AKADEMI
ÅBO 1921

ÅBO 1921
ÅBO TRYCKERI OCH TIDNINGS AKTIEBOLAG

INHALT.

DIE LICHTEMISSION UNTER DER WIRKUNG MOLELEKTRISCHER KRÄFTE AN DER OBERFLÄCHE VON KRISTALLEN.

1. AUFGABE UND GRUNDGEDANKE. Es ist zu vermuten, dass an der Oberfläche von festen Körpern, so von Kristallen, elektrische Felder aus der Oberfläche herausspringen, die beispielsweise bei katalytischen Reaktionen wirksam sind, wie Professor Haber vermutet. Stark[1] hat es für möglich gehalten, dass das Auftreten solcher molelektrischen Felder auch einen Einfluss auf Spektrallinien, die unmittelbar an der Oberfläche emittiert werden, ausüben könnte. Man kann vermuten, dass der Durchmesser dieser Felder mit dem der molekularen Wirkungssphäre (10^{-6} cm) übereinstimmt. Wenn darum solche Felder vorhanden sind, ist zu erwarten, dass elektrisch empfindliche Serienlinien (grosser Stark-Effekt) verbreitert werden, so weit ihre Emission aus einer unmittelbar an der Oberfläche liegenden (10^{-6} cm dicken) Schicht kommt. Andererseits müssten elektrisch unempfindliche Linien (kleiner Stark-Effekt), die aus einer solchen Schicht kommen, keine Verbreiterung zeigen. Zur Prüfung dieses Gedankens ist eine Methode zu finden. Erstens muss an der festen Oberfläche eine sehr intensive Lichtemission angeregt werden. Zweitens muss dafür gesorgt werden, dass ausschliesslich aus einer sehr kleinen Schichtdicke Licht zur Beobachtung kommt, dass also Licht aus grösserer Entfernung von der Oberfläche ausgeschaltet wird. Nach einem Vorschlage von Professor Stark lässt sich diese Aufgabe folgendermassen lösen. Man ver-

[1] J. Stark, Nobelvortrag: Änderungen der Struktur und des Spektrums chemischer Atome. Hirzel, Leipzig 1920. Seite 11.

wendet zur Lichterregung Kanalstrahlen, die auf eine feste Oberfläche fallen. Sie rufen zwei Wirkungen hervor: erstens spalten sie Atome von der Oberfläche ab; zweitens erregen sie die abgespaltenen Atome zur Lichtemission an. Diese leuchten am stärksten unmittelbar an der Oberfläche; die Lichtintensität nimmt mit der Entfernung von dieser ab. Um das Licht nur aus der unmittelbar an der Oberfläche liegenden Schicht zu erhalten, verfährt man folgendermassen:

Man verwendet einen festen durchsichtigen Körper, lässt Kanalstrahlen unter 45° auf die gut polierte Fläche fallen und beobachtet senkrecht zur Kanalstrahlenrichtung die Lichtemission der Oberfläche (Fig. 1). Aus nebenstehender Zeichnung ist zu ersehen, dass Licht nur aus dem Kristall oder aus der Schicht unmittelbar an seiner Oberfläche kommen kann; Licht von grösserem Abstand kann nicht austreten. Ferner wird eine Schicht, deren Dicke ungefähr gleich einer Wellenlänge des Lichtes ist, hinsichtlich der Emission der elektromagnetischen Lichtwellen an der festen Oberfläche teils zum festen Körper, teils zum Gasraum zu rechnen sein, weil eine ebene Fläche sich erst in einem Abstande, der grösser als eine Wellenlänge ist, sich definieren lässt, da ja die linearen Abmessungen der Unebenheiten von der Grössenordnung einer Wellenlänge sind. Bildet man also die Auftreffstelle der Kanalstrahlen auf der Hypotenusenfläche mit einem Objektiv, dessen Achse senkrecht zur Kathetenfläche ist, bei kleiner Öffnung ab, so ist im Bilde Licht nur vom festen Körper bezw. von der Schicht unmittelbar an der Oberfläche vorhanden; das Licht aus grösserem Abstande erscheint nicht im Bilde und kann also nicht störend einwirken. Durch okuläres Anvisieren konnte dies bestätigt werden. Im Leuchtfleck an der Oberfläche waren leicht zweierlei verschiedene Leuchten zu unterscheiden, wenn man das Auge vor der Kathetenfläche des

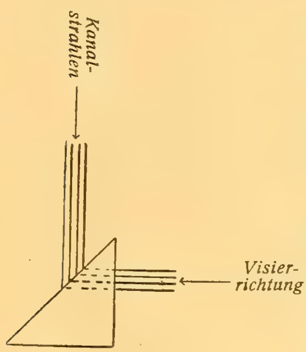


Fig. 1.

Kristalls bewegte. Das eine Leuchten erwies sich unabhängig von der Bewegung des Auges, hatte also seinen Ursprung an der Oberfläche selbst, während das andere seine Stelle veränderte, musste also vom Gasraum an der Oberfläche herrühren. Die zwei Emissionsgebiete unterschieden sich auch von einander in ihrer Farbe; das vom Kristall herrührende Licht war z. B. bei Sauerstoffkanalstrahlen auf einem Flusspatkristall bläulich, das Licht von der Schicht vor der Oberfläche rötlich.[1]

2. AUSFÜHRUNG DER METHODE. Bei den Untersuchungen wurde eine Entladungsröhre von dem aus Fig. 2 ersichtlichen Bau verwendet. Der Durchmesser der Röhre betrug 4,5 cm, der Abstand zwischen den Aluminiumelektroden 19 cm und die Öffnung in der Kathode 1,5 mm. Diese Öffnung konnte mittels einer kleinen, an der Kathodenfläche drehbar befestigten Metallscheibe von aussen mit Hilfe eines Magneten geschlossen werden, sodass die Kanalstrahlen, solange sie noch unrein

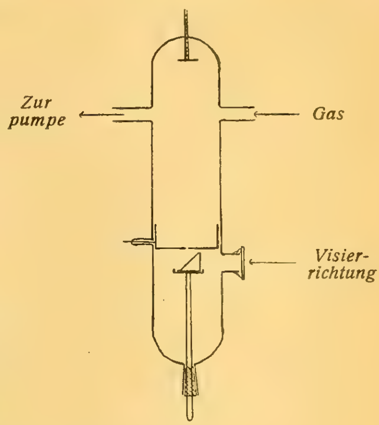


Fig. 2.

waren, verhindert wurden auf die Kristallfläche zu fallen und dieselbe mit fremden Stoffen, besonders Kohlenstoff, zu überziehen. Diese Schutzanordnung erwies sich sehr notwendig, besonders bei Wasserstoffkanalstrahlen, denn die grossen Mengen Kohlenstoff, die im Anfang in der Entladungsröhre vorhanden waren, verursachten, dass die Kristallfläche, wenn die Kathodenöffnung nicht zugeschlossen war, sehr bald mit Kohlenstoff überzogen wurde, wodurch das im Kristall erscheinende Licht in kurzer Zeit abgeschwächt wurde. Die kleinen Spuren von Kohlenstoff, die ungeachtet vielstündigen

[1] Eine ähnliche Beobachtung hat schon Goldstein gemacht. Siehe: Handbuch der Radiologie, Bd IV, S. 5.

Durchspülens mit Wasserstoff unter gleichzeitiger starker Entladungsstromstärke immer noch nicht ganz entfernt werden konnten, verursachten bei den ersten Versuchen viel Verdruss. Wegen der kleinen Lichtintensität im Leuchtfleck musste das Exponieren auf mehrere Stunden ausgedehnt werden, was wieder erfolglos blieb wegen der Abschwächung des Leuchtens mit der Zeit durch die auf der Kristallfläche niedergeschlagene Kohlenstoffschicht. So konnte ich gar keine verwendbare Aufnahme von Wasserstoffkanalstrahlenlicht auf Flusspatkristall erhalten. Erst als ich mit Sauerstoff die Röhre längere Zeit unter gleichzeitiger Entladung durchspülte, wurde der Kohlenstoff in der Röhre weggebrannt und die Kristallfläche blieb sauber während des ganzen Versuches. Erst nachdem die Röhre durch Sauerstoffentladungen gereinigt worden war, gelang es mir eine sehr gute Aufnahme von Wasserstoffkanalstrahlenlicht auf Steinsalz zu bekommen.

Unmittelbar hinter der Kathode waren die Kristalle aufgestellt. Die Lichtemission wurde an Flusspat und Steinsalz beobachtet. Die Kristalle waren in der Form eines Prismas geschliffen, dessen Durchschnitt ein gleichschenkliges rechtwinkliges Dreieck bildete. Die Länge der Kathete betrug beim Flusspat 2 cm, beim Steinsalz 1,5 cm. Um störendes Licht auszuschalten, wurden die Kristalle in dünnes Aluminiumblech eingehüllt. Auf der Hypotenusenfläche war im Metallblech eine kreisförmige Öffnung von etwa 5 mm Durchmesser ausgeschnitten, so dass die Kristallfläche frei blieb, um die Kanalstrahlen aufzufangen. In derselben Höhe war im Blech auf der vorderen Kathetenfläche eine ähnliche Öffnung angebracht, durch welche das Licht beobachtet werden konnte. Die Kristalle waren so aufgestellt, dass sie in zwei zu einander senkrechten Richtungen verschoben werden konnten, wodurch das Kanalstrahlenbündel sich leicht auf die freie Kristallfläche einstellen liess. Gleichachsig mit dem gegenüber der Kathetenfläche des Kristalles angebrachten Seitenrohr, das mit einer Glas- bezw. Quarzplatte verschlossen war, stand das Spaltrohr des Spektrographen. Im

sichtbaren Spektrum verwendete ich einen lichtstarken Zeiss-Tessar-Spektrographen (Öffnungsverhältnis 1:3,5), im Ultraviolett machte ich die Aufnahmen mit einem Steinheil-Quarz-Spektrographen (Öffnungsverhältnis 1:14). Im ersten Falle wurde der Leuchtfleck an der Kristallfläche mit einem Zeiss-Tessar-Objektiv scharf auf dem Spalt des Spektrographen im Verhältnis 1:1 abgebildet, im zweiten Falle mit einem Flusspatachromat.

Die Aufnahmen wurden auf Hauffs Ultrarapid- und Flavin-Platten genommen und die Exposition auf 5—12 Stunden ausgedehnt. Gleich nach Beendigung der Exposition wurde ein Vergleichsspektrogramm unter ganz ähnlichen Verhältnissen mit Helium- oder Quecksilberlicht genommen. Die Platten wurden mit Hauffs Rodinal entwickelt. Mit einem Hartmannschen Mikrophotometer wurden die Linienabstände und die Schwärzungsverhältnisse bestimmt.

Als Stromquelle wurde hauptsächlich eine mehrplattige Influenzmaschine verwendet. Meine Absicht war zwar, mit einer Hochspannungsdynamomaschine (3,500 Volt) zu arbeiten, aber die Spannung erwies sich zu klein, um ein zureichend intensives Leuchten an der Kristallfläche zu erzeugen. Alle Aufnahmen, die mit niedriger Spannung gemacht wurden, waren zu sehr unterexponiert, um aus ihnen einige Schlussfolgerungen zu ermöglichen. Erst bei einer Spannung von über etwa 5,000 Volt erschien der Leuchtfleck genügend intensiv.

Die Versuche wurden, wie schon bemerkt, mit Wasserstoff- und Sauerstoffkanalstrahlen gemacht. Durch Erhitzen eines im Entladungsrohr eingeschmolzenen Palladiumröhrchens mit einer Wasserstofflamme konnte das Wasserstoffgas in das Rohr hineingelassen werden, während die Gaede-pumpe gleichzeitig arbeitete. Durch Regulieren der Grösse der Flamme und der Umlaufsgeschwindigkeit der Pumpe konnte während des ganzen Versuches ein dauernder Gasstrom im Entladungsrohr unterhalten werden. Ein gleichmässiger Gasstrom war auch bei Sauerstoff, der durch elektrisches Erhitzen von Kaliumpermanganat dargestellt wurde, leicht durch Anpassen der Stärke des Hitzstromes zu erhalten.

Nach jedem Versuch wurde der Kristall aus der Röhre herausgenommen und, wenn nötig, gereinigt. An der Auftreffstelle der Kanalstrahlen war eine deutliche Vertiefung zu beobachten, die ganz glatt und durchsichtig war.[1]

3. EMISSION EINES KONTINUIERLICHEN SPEKTRUMS DURCH KANALSTRAHLEN. Mit der Erregung der Lichtemission durch den Stoss der Kanalstrahlen haben sich mehrere Forscher beschäftigt, und dabei ist u. a. festgestellt worden, dass das an festen Metallverbindungen, Salzen und Oxyden erregte Licht mehr oder minder grosse Bezirke des Spektrums kontinuierlich ausfüllt.[2] J. Stark und G. Wendt haben in einer Arbeit[3] die Frage nach dem Orte dieser Bandenemission und nach ihrem Zusammenhang mit dem Stoss der Kanalstrahlen zu beantworten versucht. Dabei sind sie zu der Schlussfolgerung gekommen, dass der Ort der Bandenemission die Gesammtheit der Auftreffstellen von Kanalstrahlenteilchen ist. Dieses direkt angeregte Licht wird dann bei seiner Ausbreitung in den festen Körper hinein in Bandenfrequenzen von Atomen des Körpers absorbiert und in diesen Banden wieder als Fluoreszenzlicht ausgestrahlt.

Auf allen meinen Aufnahmen, sowohl bei Flusspat wie bei Steinsalz, erscheint das kontinuierliche Spektrum sehr intensiv und erstreckt sich von blau bis etwa 280 $\mu\mu$. *Die Intensität nimmt nach der ultravioletten Seite stark zu.* Vermutlich geht das Spektrum weit in das Ultraviolett hinein. Dass der Ort dieser kontinuierlichen Lichtemission in der Oberfläche des Kristalles zu suchen ist, ist durch die Versuchsanordnung sichergestellt; die oben angeführte, von Stark und Wendt gezogene Schlussfolgerung in dieser Beziehung ist also durch meine Versuche bestätigt worden. Der grösste

[1] Vergl. J. Stark und G. Wendt: Über das Eindringen von Kanalstrahlen in feste Körper. Ann. d. Phys. *38.* 1912. S. 921.

[2] J. Stark: Die elementare Strahlung, S. 230.

[3] Ann. d. Phys. *38.* 1912. S. 690.

Teil des von Kanalstrahlen erregten Lichtes ist wahrscheinlich Licht der kontinuierlichen Emission und dürfte übereinstimmen mit dem von Kathodenstrahlen angeregten. In der Oberfläche werden die hohen Frequenzen am stärksten angeregt und möglicherweise wird ein Teil von diesen durch Absorption in unmittelbarer Nähe der Auftreffstelle in niedrigere Frequenzen verwandelt. In meinen Versuchen ist die Intensität von grösserer Tiefe unmerklich klein.

Durch die ungeordneten Stösse der Kanalstrahlenteilchen auf die Atome der Oberfläche, wobei die Valenzelektronen mehr oder minder aus ihren Gleichgewichtslagen abgelenkt werden und bei der Rückkehr in dieselben verschiedene Frequenzen ausstrahlen können, ist die Emission eines kontinuierlichen Spektrums verständlich. Das Nachleuchten der Auftreffstelle der Kanalstrahlen während mehreren Sekunden nach Abbrechen der Entladung, was immer deutlich beobachtet werden konnte, knüpft sich wohl an Schwingungen von allmählich in ihre Gleichgewichtslagen zurückkehrenden Elektronen.

4. AUFTRETEN VON KANALSTRAHLENLINIEN IM LICHT DER OBERFLÄCHENSCHICHT. Ausser dem kontinuierlichen Licht treten die Linien der Metalle im Kristall, Natrium und Calcium, auf. Diese stammen aus der Schicht unmittelbar an der Oberfläche. Durch diese Schicht dringen die Kanalstrahlen, bevor sie die Oberfläche treffen. Man darf also erwarten, dass ausser den Linien von Ca und Na, auch die Linien der Kanalstrahlen selber auftreten. Dies bestätigt sich in meiner Aufnahme an Steinsalz (Wasserstoff-Kohlenstoff-Kanalstrahlen). Es treten nämlich die Kohlenstofflinie $\lambda = 4270$ Å, ferner die Linien H_β und H_γ auf. Dagegen fehlen in meiner Aufnahme mit Flusspat und Sauerstoffkanalstrahlen die Sauerstofflinien. Dieses Fehlen der O-Linien ist kaum aus der geringen Intensität zu erklären, denn auf derselben Aufnahme treten sie im Kanalstrahlenspektrum, das gleichzeitig durch besondere Einstellung erhalten wurde, auf. Vielmehr rührt es vom Erlöschen der Lichtemission der Sauerstoffkanalstrahlen in der Schicht an der Kristallfläche her, wo

zahlreiche, aus dem Kristall austretende Atome vorhanden sind. Eine ähnliche Erscheinung hat Wilsar[1] beobachtet, nämlich dass Wasserstoffkanalstrahlen, in Quecksilberdampf hineingeschickt, zu leuchten aufhören; sie regen aber die Hg-Atome zum Leuchten an. Das verschiedene Verhalten der Wasserstoff- und der Sauerstoffkanalstrahlen in der Oberflächenschicht des Kristalles dürfte im elektrischen Charakter des Trägers zu suchen sein. Das Fehlen der Sauerstofflinien im Spektrogramm ist andererseits ein Beweis dafür, dass Licht aus grösserem Abstand senkrecht zur Kathetenfläche nicht austritt, sondern nur von der von Kanalstrahlen getroffenen Fläche.

5. EINFLUSS MOLELEKTRISCHER FELDER AUF DIE LINIEN VON KANALSTRAHLEN. Wenn die molelektrischen Felder an der Oberfläche eine Wirkung auf die aus dem Kristall austretenden Metallatome hervorbringen, so muss dieser Einfluss auch an den Kanalstrahlenlinien hervortreten. Es werden also im Spektrum des Leuchtfleckes elektrisch empfindliche Linien verbreitert erscheinen, elektrisch unempfindliche dagegen scharf. Dieses ist in der Tat der Fall. Die Kohlenstofflinie, $\lambda = 4270$ Å, ist scharf. Nach Mitteilung von Prof. Stark konnte er an dieser Linie, selbst in einem Feld von 100,000 Volt/cm, bei mässiger Dispersion, keine Einwirkung feststellen. Dagegen erscheint die Wasserstofflinie H_β stark verbreitert, ohne definierte Ränder. Die Lage der Linie H_γ lässt sich nur durch Auftreten eines Intensitätsmaximums feststellen; ohne erkennbare Abgrenzung geht sie in kontinuierlichen Grund über.

6. EINFLUSS MOLELEKTRISCHER FELDER AUF DIE LINIEN VON ABGETRENNTEN METALLATOMEN (Na, Ca). Wie bereits aus früheren Arbeiten[2] bekannt ist, treten im Leuchtflecke die Linien des Metalls, also in meinen Versuchen diejenigen von Ca und Na, auf. In der Tabelle 1 sind die in meinen Spektrogrammen auftretenden Calciumlinien zusammengestellt.

[1] Dissert. Würzburg 1912 und Ann. d. Phys. *39.* 1912. S. 1251.
[2] Stark und Wendt: Ann. d. Phys., *38.* 1912. S. 690.

Tabelle 1, Ca-LINIEN.

Bezeichnung	Wellenlänge in Å	Intensität	Dispersion Å/mm	Aussehen
	4586	mässig	25	Scharf
Triplet 1 N. S.	4457 4435 4425	gross	23	„
	4319 4308	mässig	22	„
	4303	gross		
	4299 4289 4283	ziemlich gross	20	„
	4227	sehr gross	18	„
Duplet H. S.	3968 3933	sehr gross	17	Nach rot verbreitert
Duplet H. S.	3737 3706	gross	15	Nach rot verwaschen
Triplet 1 N. S.	3644 3630 3624	klein	14	Geringe Unschärfe nach violett
Triplet 1 N. S.	3362 3350 3345	sehr klein	11	Unscharf, ganz verwaschen
Duplet H. S.	3179 3159	gross	9	Erste Linie nach rot verstärkt

Nach Untersuchungen von Stark und Kirschbaum[1] sind die Calcium-Linien überhaupt sehr unempfindlich gegen elektrische Felder. So konnten sie z. B., an den Linien 4586, 4457, 4435, 4425, 4227 keine merkliche Zerlegung oder Verschiebung bis etwa 30000 Volt/cm feststellen. Auch bei anderen Linien war die Verschiebung nach rot sehr klein, am grössten bei den Dupletten der Hauptserie: 3737, 3706 und 3179, 3158 in einem Betrage von etwa $0{,}_{18}$ Å.

[1] Ann d. Phys. *43.* 1914. S. 1031.

W. J. Humphreys,[1] der die Druckverschiebung der Calciumlinien untersucht hat, hat eine sehr kleine Verschiebung der meisten Linien nach rot bei einer Druckerhöhung gefunden. Bemerkenswert sind die Beobachtungen von Gale und Whitney,[2] die an den Linien 3644, 3630, 3624 und 3362, 3350, 3345 der ersten Calciumtripletnebenserie eine Druckverschiebung nach *kürzeren* Wellen fanden.

Stark hat die Erklärung aufgestellt[3], dass die Druckverschiebung von zwischenmolekularen oder molelektrischen Feldern herrührt, dass also diese Verschiebung derselben Art ist, wie die durch äussere elektrische Felder hervorgebrachte. M. Ritter[4] hat weiter festgestellt, dass das Vorzeichen der Verschiebung durch die Wirkung des elektrischen Feldes ausnahmslos mit dem Vorzeichen der Verschiebung durch Druckerhöhung übereinstimmt, was für die Richtigkeit der von Stark gegebenen Erklärung spricht. So findet Ritter u. a., dass das Calciumtriplet 3362, 3350, 3345 nach *kürzeren* Wellen um etwa 1,3 Å verschoben wird bei einem Felde von 26000 Volt/cm, also in Übereinstimmung mit den Untersuchungen von Gale und Whitney.

Aus der Tabelle 1 geht hervor, dass alle Linien von 4586 Å bis 4227 Å scharf erscheinen. Dagegen zeigen die Linien des Triplets der ersten Nebenserie, 3644, 3630 und 3624 eine geringe Verbreiterung nach violett. Das folgende Triplet hat zwar eine sehr geringe Intensität, aber erscheint ganz unscharf und verwaschen. Diese Übereinstimmung im Vorzeichen mit den oben angeführten Beobachtungen deutet auf molelektrische Kräfte an der Kristalloberfläche. Die Dupletlinien der Hauptserie sind alle nach rot verbreitert. Es ist zu vermuten, dass dieses von denselben molelektrischen Feldern herrührt. Die Lichtstärke in diesen Dupletlinien ist gross, die Dispersion klein, also günstig.

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[1] Jahrb. d. Rad. u Elektronik *5.* 1908. S. 324.

[2] Astrophys. Journal *43.* 1916. S. 165.

[3] l. c.

[4] Ann. d. Phys. *59.* 1919. S. 170.

In der Tabelle 2 sind die Linien auf der Aufnahme: Wasserstoffkanalstrahlen-Steinsalz zusammengestellt.

Tabelle 2. WASSERSTOFFKANALSTRAHLEN-STEINSALZ.

Bezeichnung	Wellenlänge in Å	Intensität	Dispersion Å/mm	Aussehen
Na H. S. D.	5896	sehr gross	90	scharf
Na 1 N	5688	gross		unscharf nach rot
Na 1 N	4984	sehr klein		stark verwaschen
H_β	4860	klein	47	verwaschen und verbreitert
H_γ	4340	klein	22	verwaschen
C	4270	klein		scharf

Die D-Linie ist, wie aus der Tabelle hervorgeht, scharf. Das erste Duplet der ersten Nebenserie hat unscharfe Ränder, ist stärker nach rot als nach violett verbreitert. Das folgende Duplet ist zu schlecht definiert, als dass man darüber etwas aussagen könnte. In Übereinstimmung mit dem Unterschied zwischen den D-Linien und denen der ersten Nebenserie steht der Unterschied des Einflusses des elektrischen Feldes auf die zwei Linienarten. Auf die D-Linien ist dieser Einfluss sehr klein,[1] dagegen ist bei der ersten Nebenserie nach Messungen von Stark und Hardtke[2] eine Verbreiterung nach rot zu beobachten.

7. ERGEBNISSE.

1:o Die von Kanalstrahlen getroffene Schicht von Flusspat und Steinsalz emittiert ein kontinuierliches Spektrum im Ultraviolett.

2:o Linien von Kanalstrahlen und von Metallatomen, welche von Kanalstrahlen von einer Oberfläche abgetrennt werden, werden in einer unmittelbar an die feste Kristallfläche grenzenden Schicht, dünner als 10^{-6} cm, so emittiert, als ob die Schicht teils dem festen

[1] Vgl. R. Ladenburg, Die Einwirkung elektrischer Felder auf Absorptionslinien (D-Linien des Na-Dampfes). Physik. Zeitschr. *22.* 1921. S. 549.

[2] Ann. d. Phys. *58.* 1919. S. 712.

Körper, teils dem angrenzenden Gasraum angehörte. Sie erscheinen, wenn sie aus dieser Schicht heraustreten, verbreitert, wenn der Effekt des elektrischen Feldes auf sie gross ist, dagegen scharf, wenn dieser Effekt klein ist. Aus dieser Übereinstimmung der Verbreiterung mit dem elektrischen Effekte darf gefolgert werden, dass die Verbreiterung von molelektrischen Feldern des Kristalles bewirkt wird.

Vorstehende Arbeit wurde im Wintersemester 1920—1921 im physikalischen Institute der Universität Würzburg ausgeführt. Es war meine Absicht, die Untersuchung weiter auszudehnen und sie quantitativ auszugestalten, ich wurde aber daran durch zwischengetretene Umstände verhindert. Immerhin dürften die bis jetzt gewonnenen Resultate trotz ihres qualitativen Charakters von Interesse sein.

Es sei mir auch hier gestattet, Herrn Prof. Stark für die Anregung zu dieser Arbeit und für die Bereitwilligkeit, mit der er alle Hilfsmittel des Institutes mir zur Verfügung stellte, meinen besten Dank auszusprechen.

Åbo, November 1921.

ACTA ACADEMIAE ABOENSIS
MATHEMATICA ET PHYSICA I:6

UEBER AZETYLCELLULOSE AUS HOLZZELLSTOFFEN

VON

Prof. Dr. ERIK HÄGGLUND,
Mag. phil. NILS LÖFMAN
UND
Dr. EDUARD FÄRBER

ÅBO AKADEMI
ÅBO 1921

ÅBO 1921
ÅBO TRYCKERI OCH TIDNINGS AKTIEBOLAG

INHALT.

EINLEITUNG.

Zu den chemischen Aufgaben, die im Kriege besondere Bedeutung gewannen, gehörte für Deutschland auch diejenige des Ersatzes von Baumwollcellulose. Er kam für zwei Industriezweige in Betracht: die Herstellung von Schiessbaumwolle und diejenige der Azetylcellulose. Die Aufgabe schien vielleicht anfangs nicht besonders schwierig zu sein; eine ausgedehnte Fabrikation bestand ja für Zellstoffe aus Holz; sie konnte also das Ausgangsmaterial und viele Erfahrungen dazu bequem liefern. Aber dieses Ausgangsmaterial kann in chemischer und hier in Betracht kommender Beziehung merkwürdig verschiedenartiges Verhalten zeigen. Bei derartig hochzusammengesetzten Stoffen bezeichnet häufig noch das gleiche Wort chemisch verschiedene Stoffe; und wenn man zur weiteren Unterscheidung diejenige der Ausgangsmaterialien benutzt, so weist dies deutlich genug daraufhin, dass hier die chemische Charakteristik noch nicht vollständig gelungen ist. Man darf wohl selbst im Hinblick auf die neuste Veröffentlichung von Emil Heuser und E. Bœdecker[1] sagen, dass die Frage nach der chemischen Eigenart von Cellulose verschiedener Herkunft noch nicht endgültig beantwortet ist. Andererseits braucht die technische Verwendung dieses Materials auf einen derartigen wissenschaftlichen Bescheid nicht zu warten; gerade sie liefert dann vielmehr Beiträge dafür, indem sie das Verhalten in der speziell verfolgten Richtung genauer feststellt.

Sowohl bei der Herstellung von Schiessbaumwolle als auch bei der Azetylierung ergaben sich in der Tat besondere Verhältnisse, wenn statt der Baumwolle Cellulose anderer Herkunft verwendet wurde. Nach vielen, zum Teil Jahrzehnte zurück liegenden Untersuchungen sind die Schwierig-

[1] Emil Heuser und E. Bœdecker, Beiträge zur Kenntnis der Holzcellulose. Z. f. angew. Chem. *34*. 461 (1921).

keiten für die erstere Fabrikation wohl überwunden[1]. Da erwies sich Sulfitzellstoff als geeigneter denn Natronzellstoff.

Über die Azetylierung von Holzzellstoff hat jüngst W. Nauck[2] eine kurze Mitteilung veröffentlicht. Er betont darin den Einfluss der Oberflächenbeschaffenheit und hält sie für massgebend für den Ausfall der Versuche; die Herstellung von Films gelang ihm.

Wir haben, vor einigen Jahren beginnend, derartige Azetylierungen genauer untersucht und können jetzt über die hauptsächlichsten der dabei erhaltenen Resultate berichten. Als Ausgangsmaterialien verwendeten wir Fichtenholz, Sulfitzellstoff, Filtrierpapier. Nach verschiedenartigen Vorbereitungen dieser Stoffe wurden sie Azetylierungen nach bekannten und davon abweichenden Methoden unterzogen. Dabei stand das praktische Interesse im Vordergrunde; manchen neuen Erscheinungen konnte nicht in wissenschaftlicher Vollständigkeit nachgegangen werden. Es gelang schliesslich auch aus Sulfitzellstoff oder Filtrierpapier Präparate herzustellen, die als Lacke oder Filme brauchbar waren. Wir beschreiben im folgenden aber auch diejenigen Versuche, die dieses Ergebnis nicht hatten, soweit dabei in anderer Hinsicht interessierende Beziehungen zu Tage traten.

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[1] Vgl. z. B. August Schrimpff, Nitrocellulose aus Baumwolle und Holzzellstoffen. Sonderdruck aus der Zeitschr. f. d. ges. Schiess- und Sprengstoffwesen, 14. Jahrg. 1919 (J. F. Lehmanns Verlag, München 1919); darin ein historischer Rückblick, der den Anteil Wilhelm Wills wenig berücksichtigt. Ferner: S. D. Wells und V. P. Edwards, Die Verwendung von Holzzellstoff zur Gewinnung von Nitrocellulose. Paper, 12 Febr. 1919 (vgl. Cellulosechemie II 8 (1921).

[2] W. Nauck, Beitrag zur Frage der Azetylierung von Zellstoffen. „Cellulosechemie", Wissenschaftl. Beibl. z. d. Zeitschr. „Der Papierfabrikant", II 61 (1921).

1. METHODEN ZUR DARSTELLUNG UND KENNZEICHNUNG VON AZETYLCELLULOSE.

„Wohl auf keinem Gebiete der chemischen Technik dürfte der Umfang der geleisteten Arbeit, die Grösse der aufgewandten Kosten, die Mannigfaltigkeit der erfinderichen Tätigkeit, die Anzahl der Patentanmeldungen und vor allem die Höhe der in die Entwicklung dieses Arbeitsgebietes gesetzten Erwartungen in solchem Missverhältnis zu dem erzielten Resultat stehen, wie auf demjenigen der Azetylcellulosen.“ [1] Es handelt sich ja bei der Azetylierung um einen Komplex von Reaktionen, die z. B. noch von mechanischen Einflüssen stark abhängig sind. Hat man das Azetylierungsgemisch selbst, aus Eisessig und Essigsäureanhydrid bestehend, festgelegt so bleibt noch die Wahl der Katalysatoren, der Temperatur und Zeitdauer für die eigentliche Veresterung, ausserdem auch die Wahl der Art wie man durch Hydrolysierung den Estern eine günstige Löslichkeit erteilt. Wenn so viele Faktoren variierbar sind, wenn die Zahl der „Freiheitsgrade“ anscheinend so ausserordentlich gross ist, gibt es natürlich eine Fülle von verschiedenen Versuchsmöglichkeiten. Temperatur und Dauer der Reaktion sind allerdings nicht, ganz unabhängig variierbar: wenigstens dann nicht, wenn man auf die Erzeugung von Triazetat hinarbeitet. Bei zu starken Einwirkungen geht die Veresterung weiter unter gleichzeitigem Abbau des Moleküls bis zu dem Cellobioseoktazetat. Aber lang vor seiner Bildung schon hört das Produkt auf, zu der vorgesehenen tech-

[1] A. Eichengrün, Ullmann's „Enzyklopädie d. techn. Chemie“ I. 114 (1914).

nischen Verarbeitung geeignet zu sein. „Die spröden amorphen Azetate, welche man bei zu lang dauernder Einwirkung des Azetylierungs-Gemisches auf Cellulose in der Kälte erhält, die sich spielend leicht zu dünnen Flüssigkeiten in Chloroform lösen, verdanken ihre Entstehung anerkanntermassen der zu weit fortgeschrittenen Hydrolyse des Cellulosemoleküls“.[1] Ob man aber die „Azetylierung“ (wenn diese Bezeichnung für den ganzen Komplex der Reaktionen gelten soll) an der geeigneten Stelle unterbrochen hat, das erkennt man erst bei der endgültigen Aufarbeitung. Besonders aufmerksam muss man da den rascheren Verlauf bei den höheren Temperaturen verfolgen. Da man es mit Reaktionen in heterogenen Systemen zu tun hat, so kommt auf die mechanische Beschaffenheit der Cellulose sehr viel an.

Gross ist auch die Bedeutung der sogenannten Katalysatoren bei diesem Prozesse. Von all den als solche wirkenden Körpern ist ihre Fähigkeit, mit Wasser Verbindungen einzugehen, bekannt und darum wohl zunächst auch beim Versuche einer Erklärung ihres Wirkens zuerst bedacht worden. Aber nach der Zusammensetzung der Gemische kann es sich gar nicht um das Freiwerden von Wasser handeln.[2] Die katalysierenden Zusätze sind zugleich auch für sich Lösungsmittel der Cellulose, oder sie stehen wenigstens solchen sehr nahe. So hat man denn auch diese Eigenschaft als ihre für den Azetylierungsprozess entscheidend wichtige hingestellt. Es dürfte sich aber damit wohl ähnlich verhalten, wie es für manche anderen katalytischen Prozesse E. Färber entwickelt hat.[3] Der Katalysator, als ein Stoff der unter gewissen Bedingungen mit dem Ausgangsmaterial zu reagieren vermag, öffnet das Valenzfeld desselben in spezifischer Weise, und muss dann, u. a. auch seiner geringen Menge wegen, anderen anwesenden Komponenten die eigentliche, zu der

[1] H. Ost, Zeitschr. f. angew. Chem. *19.* I. 997 (1906).

[2] Vgl. dazu auch H. Ost, Zeitschr. f. angew. Chem. *32.* 67 (1919).

[3] E. Färber, Inaug. Diss. Leipzig 1916, S. 43 ff. (erscheint demnächst in Ann. d. Chem.); ferner auch „Die Naturwissenschaften“ *8.* 324 (1920).

neuen Verbindung führende Reaktion überlassen. Unter diesen Gesichtspunkten gewinnt Ost's Nachweis[1] einer anteiligen Bildung von Cellulose-Schwefelsäure-Estern aus schwefelsäurehaltigen Ansätzen besonderes Gewicht. Die so entstandenen Ester sind zumeist löslich in Chloroform, aber unlöslich, oder nicht „echt", d. h. nicht wiederholbar löslich in Aceton oder Essigester. Dafür wendet man nun die „Hydrolyse" an: Man setzt nach Beendigung der Reaktion kleine Mengen Wasser, wässrige Säure oder Alkalilösung zu, und erhitzt einige Zeit lang. Auch diesen Vorgang hat Ost näher untersucht.[2] Er kennzeichnet ihn, übereinstimmend mit früheren Veröffentlichungen anderer Forscher, als eine teilweise Verseifung.

Die Durchführungen im einzelnen sind vor allem in zahlreichen Patentschriften beschrieben worden. Statt einer systematischen Aufzeichnung[3] derselben sollen hier nur diejenigen erwähnt werden, die für unsere Untersuchungen Bedeutung gewannen.

Lederer geht nach D. R. P. 118538 (1899), 120713 (1899) und 163316 (1901) von Hydrocellulose aus, die für sich oder in dem Azetylierungsgemisch selbst erzeugt wird. Er erkannte auch den Einfluss der Temperatur auf die Eigenschaften des Produktes. Eichengrün und Becker, die ebenfalls auf die Temperatur besondere Rücksicht nehmen, benutzen dagegen unveränderte Cellulose (D. R. P. 159524 [1901] Bayer), als Katalysator diente wie bei Lederer Schwefelsäure. Miles (Am. Patent 838350 [1905]) und die Firma Bayer (D. R. P. 252706 [1905]) haben dann die sogenannte hydratisierende Nachbehandlung erfunden, die zu einem in Aceton löslichen Produkte führt. Die Bad. Anilin und Sodafabrik verwendet nach D. R. P. 184145 (1904) feuchte Baumwolle. Knoevenagel

[1] Vgl. Ost. Z. f. angew. Chem. *32.* 69 (1919).

[2] 1 c. S. 82 ff.

[3] Vgl. dazu u. a. die auf S. 5 zitierte Abhandlung von Eichengrün, ferner etwa Edward C. Worden, Technology of Cellulose Esters, Bd. 8 New-York (1916), dazu auch „Kunststoffe" *11.* 1—5 (1921).

(Knoll & C:o) hat sich u. a. in D. R. P. 203178 (1906) die Verwendung von neutralen, von Alkalisalzen verschiedenen Salzen, vor allem Chlorzink schützen lassen. (Vgl. ferner D. R. P. 303530 [1912]). Die Agfa behandelt die Cellulose zuvor in einem Schwefelsäure-Salpetersäuregemisch von grösserem Wassergehalte (D. R. P. 295889 [1911]). Alfred Wohl mischt und presst die Baumwolle mit Eisessig vor der Azetylierung (F. P. 448072 [1912]).

Zahlreiche weitere Abänderungen der Verfahren beim Azetylieren und darauffolgendem Hydratisieren sind in Patenten niedergelegt. An diesen Reaktionen die man im einzelnen noch so wenig durchschaut, ist eben immer das Endprodukt das Massgebend Interessante gewesen. So gehört denn besonders zur Herstellung dieser Präparate diejenige „Uebung", die immer, wenn sie in dieser Weise bedingend für den Erfolg ist, einen Mangel an wissenschaftlicher Durchdringung der Verfahren kennzeichnet.

Die *analytische Charakteristik* der Azetylcellulose bezieht sich natürlich auf den Azetyl-Gehalt in erster Linie. Dafür haben ja die Untersuchungen von Ost [1] die besten Methoden gegeben. Die alkalische Verseifung liefert hier leicht Zersetzungsprodukte, die das Resultat störend beeinflussen; wir haben denn auch im folgenden die saure Hydrolyse nach Ost zur Azetylbestimmung angewandt.

Abweichend von andern Autoren geben wir im folgenden stets „Azetyl"-zahlen an, d. h. den prozentualen Gehalt an CH_3 CO, während sonst oft auf Essigsäure, also CH_3 COOH berechnete Zahlen mitgeteilt werden.

Das Diazetat der Cellulose enthält $34{,}97$ % CH_3 CO, entspr. $48{,}8$ % CH_3 COOH; für Triazetat sind die Werte: $44{,}8$, bezw. $62{,}5$ %; für Tetraazetat $52{,}1$, bezw. $72{,}7$.

Aber bei gleichem Azetylgehalte können Azetylcellulosen sehr verschiedenartig und verschiedenwertig sein. Es kommt nicht nur darauf an, ein Triazetat herzustellen; wesentlich ist ausserdem, in

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[1] Ost, Z. f. angew. Chem. *19*. I. 996 (1906).

welcher Art die Cellulose dabei verändert wurde. Das äussert sich in der Beziehung der Azetylcellulose zu verschiedenen Lösungsmitteln und in der Viskosität der Lösungen. Während die geschichtlich ersten Präparate hauptsächlich in Chloroform sich lösten, ging später das Bestreben — durch Miles zuerst erfüllt — dahin, Aceton als Lösungsmittel zu benutzen. Eichengrün hat dann die Löslichkeit in Gemischen von Benzol und Alkohol entdeckt und gebraucht. Wir prüften auch das Verhalten gegen andere Flüssigkeiten und Gemische, wie sie beim Filmgiessen angewendet werden.

Ein weiteres analytisches Merkmal hat man in dem Reduktionsvermögen gegenüber Fehlingscher Lösung. Die „Kupferzahl", nämlich die von 100 g der veresterten Cellulose ausgeschiedenen Gramm Kupfer,[1] wäre natürlich bei einer ganz streng nur veresterten Cellulose kleiner als 1; in Wirklichkeit erhält man jedoch mehrfach grössere Zahlen, und zwar hat darauf nach unseren Versuchen die Endphase, die Hydrolyse der Azetylcellulose, keinen bemerkenswerten Einfluss.

2. FICHTENHOLZ ALS AUSGANGSMATERIAL.

HERSTELLUNG DER CELLULOSE AUS KONZENTRIERT SALZSAUREN LÖSUNGEN.

Aus den trockenen Sägespänen isolierten wir zunächst die Cellulose mit Hilfe von hochkonzentrierter Salzsäure. Nach 42 stündigem Stehen mit der fünffachen Menge 40 %-iger Salzsäure wurde das Filtrat in Wasser gegossen. Die ausgeschiedene Cellulose, von HCl und Wasser befreit, löste sich dann in verschiedenen Azetylierungsgemischen auf und gab stets ungeeignete Films, aber dies wenigstens mit einigen bemerkenswerten Unterschieden.

Die Azetylgehalte waren auffallend niedrig, wenn nach den Angaben von Miles Schwefelsäure als Katalysator gedient hatte: sie

[1] Wir bestimmten sie nach dem Verfahren von Hägglund, Der Papierfabrikant, *17*, 301 (1919).

stiegen nicht über 26%! Chloroform löste die Azetylcellulosen nicht, wohl aber Aceton; diese Lösungen waren aber nur sehr wenig viskos.

5 g Cellulose, 12 g Essigsäureanhydrid, 20 g Eisessig wurden unter Kühlung mit 0,5 g conc. Schwefelsäure versetzt. Nach verschieden langer Aufbewahrung bei Zimmertemperatur erfolgte die Hydrolyse durch 2 g einer Mischung gleicher Teile von Wasser und Eisessig mit Zusatz von 5% Schwefelsäure bei 50° in 12 Stunden:

Dauer der Aufbewahrung nach Eintritt der Auflösung	Azetylgehalt	Kupferzahl
5 Stunden	26,0 %	—
10 „	25,8 „	—
20 „	25,1 „	22,4
40 „	24,8 „	14,3

Ein Vergleichsversuch mit reinster Watte führte zu einer guten Azetylcellulose. Ihr Azetylgehalt betrug 41,7 %, Cu-Zahl = 9,8; aus der viskosen Azetonlösung entstand ein klarer, zäher Film.

Eine genaue Diskussion der Ursachen für den so spärlichen Eintritt der Veresterung ist vorläufig unmöglich; mit anderen Katalysatoren gab dieselbe Cellulose wenigstens in Bezug auf die Menge des eingetretenen Azetyls normale Resultate; weiterhin wird noch zu beschreiben sein, dass eine etwas anders behandelte, durch Salzsäure aus Holz gewonnene Cellulose in einer anders zusammengesetzten Reaktions-Mischung ebenfalls höheren Acetylgehalt aufwies, obwohl dabei wieder Schwefelsäure den Katalysator bildete.

Mit *Natriumäthylsulfat* als Katalysator erhielten wir wieder nur unelastische Films, entsprechend der geringen Viskosität der Azeton-Lösungen. Aber die Azetylierung hatte doch offenbar einen ganz anderen Verlauf als mit Schwefelsäure genommen. Die Azetylzahlen blieben oft über 44%; sie sanken jedoch bei längerer Ausdehnung der Hydrolyse. Wir können damit auch an diesen Präparaten den

Befund von Ost an seinem ganz andersartigem Material bestätigen. Ansatz:

5 g Cellulose, 20 g Essigsäureanhydrid, 25 g Essigsäure, $0{,}5$ g Natriumäthylsulfat.

Azetylierung I: bei 70° bis zur vollständigen Auflösung der Cellulose.

Hydrolyse: Nach Zusatz von 4 ccm Wasser bei 55° und folgenden Zeitdauern:

Hydrolysenzeit	Azetylgehalt	Kupferzahl
5 Stunden	$45{,}2$	$16{,}6$
29 „	$44{,}3$	$16{,}0$
51 „	$43{,}5$	$16{,}6$

Ansatz: wie soeben

Azetylierung II: zuerst bei Zimmertemperatur; als nach 90 Stunden jedoch keine vollständige Lösung erzielt war, wurde noch 25 Stunden lang auf 70° erhitzt.

Hydrolyse: wie soeben

Hydrolysendauer	Azetylgehalt	Kupferzahl
5 Stunden	$45{,}2$	$13{,}6$
30 „	$43{,}9$	$19{,}4$
100 „	$39{,}4$	$14{,}4$

Bei Ansätzen *ohne Eisessigzugabe* trat auch nach langer Einwirkung keine Lösung ein. Aehnlich ging die Reaktion mit *Chlorzink* als Katalysator von statten. Mit zunehmender Hydrolysendauer nahmen die azetylierten Lösungen an Viskosität ab; die Azetylzahlen sanken von $47{,}7$ % auf 40 % (nach 60 Stunden Hydrolyse bei 100°).

VORBEHANDLUNG DER HOLZCELLULOSE MIT SCHWEFELSÄURE-SALPETERSÄUREGEMISCH.

Nach den bisher mitgeteilten Versuchen hätte man schliessen können, dass die aus salzsaurer Lösung gewonnene Cellulose kein geeignetes Ausgangsmaterial für gute Films ist. Ehe wir diese Methode verliessen, wollten wir jedoch noch den Einfluss von Vorbehandlungen dieser Cellulose feststellen. Dafür liess sich z. B. das Verfahren der Agfa anwenden. Wenn danach die Cellulose durch verdünnte Nitriersäure „angeätzt“ und nach dem Auswaschen wieder getrocknet war, trat wohl mit *Schwefelsäure* als Katalysator keine sichtbare Azetylierung ein; aber schon mit verhältnismässig sehr wenig *Chlorzink* im Azetylierungsgemisch erhielten wir in normaler Zeit Auflösung der Cellulose. Allerdings entstand ein in den üblichen Medien unlösliches Produkt und angenähert dem Azetylgehalte des Tetraazetats: Diese Vorbehandlung hat also die Präparation ungünstig beeinflusst.

Ansatz:
5 g „vornitrierte“ Cellulose, 20 g Eisessig, 25 g Essigsäureanhydrid, 0,5 g $ZnCl_2$.
Azetylierung: 23 Stunden bei 50°.
Hydrolyse: mit 2 g Wasser 14 Stunden bei 50°.
Azetylgehalt: 49,0 %; Kupferzahl 19,0.

VORBEHANDLUNG MIT EISESSIG.

Ein wenig besser verlief die Reaktion mit denjenigen Cellulosen, die zuvor dreimal mit Eisessig gewaschen waren. Allerdings ist damit nicht gemeint, dass nun Films von den gewünschten Eigenschaften erzeugt werden konnten. Doch löste sich wenigstens mit Schwefelsäure bezw. Natriumäthylsulfat als Katalysator die Cellulose im Azetylierungsgemisch auf; bei Zimmertemperatur waren dazu nur 2—3 Stunden erforderlich.

Die Hydrolyse mit Wasser oder wässriger Kaliumhydroxyd-Lösung führte jedoch auch nach 50—60 Stunden bei 50° nicht zu Produkten von normaler Löslichkeit. Dem entsprach auch die zu geringe Viskosität der ursprünglichen essigsauren Lösungen.

Bei einer der Versuchsreihen hatte die vorbehandelte Cellulose die Kupferzahl 14,6. Die Ester daraus, die sich zumeist beim Fällen der ursprünglichen Lösungen in groben Flocken ausschieden, ergaben z. B. 49,4 % Azetyl, 17,7 Cu-Zahl; 48,0 % Azetyl, 16,4 Cu-Zahl; 48,0 % Azetyl, 20,0 Cu-Zahl; 44,1 % Azetyl, 14,8 Cu-Zahl; 43,0 % Azetyl, 14,1 Cu-Zahl.

Diese Ausfällungen lösten sich nur beim *Erwärmen* in Aceton oder Chloroform, am leichtesten noch in der Mischung aus 8 Teilen Aceton und 15 Teilen Milchsäureäthylester („Acetonmischung").

Andere Cellulosepräparate mit höheren und niedrigen Kupferzahlen verhielten sich im wesentlichen ähnlich. Man sieht daran nur wieder, wie sehr derartige analytische Bestimmungen der Ergänzung durch andere bedürfen, wenn es sich um einigermassen vollständige Kennzeichnung handeln soll.

3. SULFITZELLSTOFF ALS AUSGANGSMATERIAL.

Sulfitzellstoff ist kein einheitlicher Stoff, Lignin und Pentosane, zuweilen auch Hydro- und Oxycellulose, mineralische Bestandteile können darin in kleineren oder grösseren Mengen vorhanden sein.

Es ist nicht leicht, diese Fremdstoffe zu entfernen, ohne die Cellulose chemisch zu verändern. Die behutsame Einwirkung von Aetzalkali und von Oxydationsmitteln kann zum Ziel führen. Wir versuchten die Reinigung zunächst allein mit Oxydantien, wie Chlorwasser, Permanganat, mit darauffolgender sorgfältiger Auswaschung der organischen und anorganischen löslichen Produkte. So wurde Sulfitzellstoff nach insgesamt 4-stündiger Behandlung mit Chlorwasser bei Zimmertemperatur, unterbrochen durch kalte alkalische

Auswaschungen, mit der Kupferzahl $5{,}_{69}$ erhalten; bei Verdoppelung der gesamten Einwirkungszeit sank dieser Wert nur wenig, auf $5{,}_{05}$. Die kurze Einwirkung von 5 % Königswasser führte zu einem Präparat von der Kupferzahl $2{,}_{10}$. Die 40-fache Menge 3 %-igen Wasserstoffsuperoxydes, das in 100 ccm 10 ccm 24 %-iges Ammoniak enthält, blieb in anderen Versuchen einige Stunden in guter Berührung mit Zellstoff; die Kupferzahl betrug dann z. B. $3{,}_{42}$. 1 %-ige Kaliumpermanganat-Lösung wirkte mit ähnlichen Ergebnissen ein. Auch vorheriges Behandeln mit Natronlauge löste nicht alle die Fehlingsche Lösung reduzierenden Substanzen aus dem Zellstoff heraus. Dabei wurden 100 g Zellstoff mit 400 ccm 2 %-iger Natronlauge eine halbe Stunde lang geknetet, gründlich mit Wasser, dann verdünnter Salzsäure ausgewaschen, 40 Minuten lang Chlorgas durchgeleitet, während ³/₄ Stunden mit 6 %-iger Natronlauge bei 45° behandelt und ausgewaschen, gegebenenfalls auch mit Kaliumpermanganat und dann Natriumbisulfitlösung nachgebleicht. Ein Zellstoff, der vor dieser Reinigung $5{,}_{58}$ als Kupferzahl hatte, wies danach den Wert von $4{,}_{63}$ auf.

Die Reduktionswerte blieben also im Vergleich zu Baumwolle noch ziemlich hoch. Die folgenden Versuche wurden zumeist mit durch Chlorwasser mit oder ohne vorherige alkalische Behandlung gereinigten Zellstoffen vorgenommen.

Bei den ersten zahlreichen Versuchen mit Sulfitzellstoff entstanden zumeist Produkte mit Azetylgehalten zwischen 48 und 52 %, fast unabhängig von der Art des angewandten Verfahrens. Man muss annehmen, dass darin zum Teil Tetraazetate vorlagen. Die Versuche, mit Schwefelsäure zu azetylieren, brachten keine befriedigende Resultate, sowohl wenn nach Miles gearbeitet wurde, als auch bei einer an H. P. A. 7056 (1917) sich anlehnenden Abänderung, wobei das Essigsäureanhydrid, allein oder im Gemisch mit der kleinen Schwefelsäuremenge, erst nachträglich zugesetzt wurde. Auffallend hoch war der Reduktions-Wert gegenüber Fehlingscher Lösung: Neben Kupferzahlen von 13—14 lagen auch Werte wie 18, 21,

24 vor. Die Löslichkeiten waren gering und die Films brüchig. Diese Ergebnisse änderten sich zuerst nur in kleinen Einzelheiten und nicht in entscheidend günstiger Weise, als der Sulfitzellstoff zuvor mit Eisessig gewaschen und darauf getrocknet wurde. Wohl aber gelang es mit Chlorzink oder Natriumäthylsulfat (den Katalysatoren, die Knoll nennt) gute Films herzustellen. Diese hatten auch sehr viel kleinere Kupferzahlen; die Azetylgehalte dagegen blieben manchmal noch in der Nähe derjenigen für Tetraazetate berechneten.

5 g Cellulose, mit Eisessig gewaschen und getrocknet;
20 g Eisessig, 25 g Essigsäureanhydrid,
$1{,}_{25}$ g Natriumäthylsulfat:

Nach 22 Stunden bei 70° ist Lösung eingetreten; die nachfolgende Hydrolyse (mit Zusatz von 4 ccm Wasser) dauerte 29 Stunden bei 50°. Die Ausfällung, die in guter Ausbeute entstand, war hell und bildete Fladen.

Azetyl-Gehalt: $45{,}_{2}$ %; Kupfer-Zahl: $5{,}_{25}$. Chloroform löste nicht; Aceton, allein und im Gemisch mit Alkohol, gab beim Erwärmen Lösungen, aus denen klare, elastische Films entstanden.

Bei verlängerter Hydrolysendauer, nämlich nach 72 Stunden, waren die Löslichkeiten zwar annähernd dieselben geblieben; aber der Azetylgehalt war auf $43{,}_{4}$ % gesunken, die Kupferzahl auf $14{,}_{66}$ gestiegen. Die Films waren trotzdem noch ziemlich elastisch.

Das dabei verwendete Natriumäthylsulfat stammte von Merck (Darmstadt). Merkwürdig abweichend verhielt sich ein Präparat der Firma Kahlbaum (Berlin); die Auflösung der Cellulose im Azetylierungsgemisch dauerte nämlich in seiner Anwesenheit gelegentlich sechs Mal so lange wie mit jenem ersten Stoff und trat manchmal überhaupt nicht ein. Vermehrung des Essigsäureanhydrid-Anteils setzte die Reaktionsdauer beide Male herab. Aber der schlechtere Katalysator arbeitete immer noch vier Mal so langsam wie der andere. Beispielsweise wurden 5 g Cellulose mit 20 g Eisessig und den in der Tabelle angegebenen verschiedenen Essigsäureanhydrid-

Mengen bei 70° stehen gelassen; die Menge des Katalysators blieb stets 1,25 g in jedem Ansatz. Nach der Auflösung wurde mit Zusatz von 4 ccm Wasser 48 Stunden bei 50° hydrolysiert.

Essigsäure-anhydrid g	Präparat Merck: Auflöse-Zeit Stunden	Präparat Merck: Löslichkeit in Aceton	Präparat Kahlbaum: Auflöse-Zeit Stunden	Präparat Kahlbaum: Löslichkeit in Aceton
25	64	gut	410	trüb lösl.
35	35	gut	190	unvollständig löslich
50	17	gut	68	wenig lösl.

Auch mit dem ersten Präparate ist hier die Auflösungszeit beträchtlich. Sie konnte durch gute Verteilung der Cellulose und häufiges Bewegen des Ansatzes, besonders auch durch Einsaugen der Azetylierungsmischung in die evakuierte Cellulose, stark herabgesetzt werden, z. B. auf 24 Stunden. Der Unterschied in der Wirkungsweise der beiden Katalysatoren blieb dennoch bestehen, ja er trat noch verstärkt zu Tage. Daran änderte sich auch nichts, als statt praktisch ganz trockener Cellulose solche von 3 und 6 % Wasser-Gehalt verwendet wurde.

Von Natriumbisulfat reichten 0,1 g, zu der Mischung von 5 g Cellulose, 20 g Eisessig und 25 g Essigsäureanhydrid zugesetzt, nicht aus um eine Auflösung zu erzielen. Wenn ausserdem noch 0,5 g Natriumäthylsulfat Kahlbaum anwesend war, erhielt man nach 206 Stunden (70°) Azetylierung und darauffolgender Hydrolyse einen in Aceton und Acetonmischung schwerlöslichen Ester und brüchige Films. Besser wirkte die Mischung mit 0,2 g Natriumbisulfat + 0,5 g Natriumäthylsulfat, doch war die Auflösedauer noch immer ähnlich hoch. Vom Natriumbisulfat allein genügten auch 0,5 g nicht; erst mit 1 g davon war nach 28 Stunden (70°) Lösung eingetreten, und die hydrolysierte Azetylcellulose gab aus Acetonmischung einen guten Film.

Die Azetylierung ist auch insofern abhängig von der „Vorgeschichte“ der Cellulose, als gewisse Vorbehandlungen mit einzelnen Komponenten der Azetylier-Gemische oder anderen organischen Flüssigkeiten die Dauer der Veresterung, gelegentlich sehr stark, beeinflussen. Wenn die trockene Cellulose mit Eisessig vermischt mehrere Stunden lang (z. B. 24) bei gewöhnlicher Temperatur aufbewahrt wurde, so machte sich kaum ein Einfluss auf die nachfolgende Reaktion bemerkbar. Geschah die Aufbewahrung bei 70° ca. 18 Stunden lang, so ging die Azetylierung mit Natriumbisulfat ($0{,}_5$ g + $0{,}_5$ g Wasser auf den üblichen Ansatz mit 5 g Cellulose) als Katalysator unverkennbar beschleunigt vor sich; die Auflösung im Azetylierungsgemisch erfolgte in durchschnittlich 4 Stunden bei 70°, während sie sonst eine etwa 3—6 Mal so lange Zeit beanspruchte.

Sehr hindernd wirkte aber die Vorbehandlung mit dem Gemisch von Eisessig und Essigsäureanhydrid bei hoher Temperatur. 20 g Cellulose wurden mit 80 g Eisessig und 120 g Essigsäureanhydrid am Rückflusskühler gekocht; dabei war natürlich für Fernhaltung von Feuchtigkeit gesorgt. Nach dem Abkühlen kamen $2{,}_5$ g Natriumäthylsulfat (von M e r c k, Darmstadt) als Katalysator hinzu. Hatte das Kochen $1^1/_2$ Stunden gedauert, so vergingen 116 Stunden bis zur Auflösung, die sonst bei derselben Temperatur (70°) etwa 12 Stunden dauern kann. 2-stündiges Kochen verzögerte die Azetylierungsdauer noch mehr, und nach 3 Stunden langem Sieden trat überhaupt keine Auflösung mehr ein.

Zur Erklärung könnte man zunächst daran denken, dass die Erhitzung in diesem Gemisch zu einem Abbau der Cellulose geführt hätte. Ein solcher ist nicht nachweisbar, wenigstens wenn man die Kupferzahlen als Kriterium benutzt. Merkwürdigerweise wird die starke Reaktionsverzögerung zum Teil aufgehoben, wenn man nach dem Kochen ganz wenig Wasser zusetzt. Proben von je 5 g Cellulose wurden mit 20 g Eisessig und 30 g Essigsäureanhydrid 2 Stunden gekocht; nach dem Abkühlen kamen je $1{,}_{25}$ g Natriumäthylsulfat hinzu, und in die eine der Mischungen ausserdem noch

0,1 ccm Wasser. Nach dreitägiger Aufbewahrung war nur in der mit Wasser versetzten Probe Auflösung eingetreten.[1]

Uebrigens wirkte auch vorheriges Kochen mit Chloroform, Acetylentetrachlorid oder Alkohol ähnlich wie das Kochen mit Eisessig-Essigsäureanhydrid-Gemisch. Eine Cellulose mit der Kupferzahl 5,02 behält diesen Wert auch bei, nachdem sie eine halbe Stunde lang mit einer der genannten organischen Flüssigkeiten gekocht worden war. Die nachfolgende Azetylierung mit Natriumbisulfat als Katalysator, die sonst bei 70° in etwa 10 Stunden zu der Auflösung der Cellulose führte, beanspruchte hier 140—200 Stunden bei derselben Temperatur.

Anders wirkten diejenigen Vorbehandlungen, bei denen die Cellulose zunächst mit den entsprechenden Mengen von Eisessig und Katalysator zusammengebracht wurde. Man liess dann die Mischung mehrere Stunden je nachdem bei Zimmertemperatur oder bei 50—70° stehen und fügte danach erst die nötigen Mengen Essigsäureanhydrid zu.

Wenn dabei *Schwefelsäure* der Katalysator war, so bedingte die Dauer der Vorbehandlung diejenige der Auflösung im Azetylierungsgemisch. 5 g Zellstoff wurde mit 20 g Eisessig und 0,25 g konc. Schwefelsäure bei Zimmertemperatur bezw. 16, 20, 50 Stunden aufbewahrt. Nach Zusatz von 25 g Essigsäureanhydrid dauerte dann die Auflösung bei Zimmertemperatur entsprechend 30, 25, 20 Stunden. Die hydrolysierten Produkte hatten Azetylgehalte von etwa 46 %; die Kupferzahl derselben war von etwa 4 auf etwa 7 gestiegen; die Löslichkeit in den üblichen Medien war aber nicht immer günstig, und der Film liess zu wünschen übrig.

[1] Letzthin ist ein Patent des Vereins für Chemische Industrie in Mainz, Frankfurt a/Main D. R. P. 339824, Kl. 12 o, Verfahren zur Herstellung von Celluloseazetat, erteilt worden, nach welchem man zur Erzielung eines wasserfreien Ausgangsmaterials die Mischung von Cellulose, Essigsäureanhydrid, Eisessig oder einem anderen Verdünnungsmittel längere Zeit einwirken lässt, ehe man den zur Veresterung erforderlichen Katalysator hinzufügt.

Versuche mit einer vorher „hydrolysierten" Cellulose nach dem Verfahren von Lederer führten nicht zu guten haltbaren Films; Ost beschreibt[1] das Verhalten von Watte bei zweistündiger Einwirkung von Eisessig (achtfache Menge) und Schwefelsäure (40 % vom Cellulosegewicht); die Watte war dann stark brüchig geworden, ohne dass die Elementaranalyse eine Veränderung sicher zu erkennen gestattete. Wir liessen Eisessig und Schwefelsäure in demselben Verhältnis wie angegeben verschiedene Zeiten lang auf Sulfitzellstoff einwirken. Die Flüssigkeit wurde dann abgesaugt und die Cellulose durch Zugabe der üblichen Mengen Eisessig und Essigsäureanhydrid bei Zimmertemperatur azetyliert. Nach der Auflösung wurde dann in der einen Serie sofort mit Wasser gefällt, in der anderen vorher erst 12 Stunden bei 50° hydrolysiert.

Azetyl-cellulose	Azetyl-Gehalt	Kupfer-Zahl	Löslichkeit		
			Aceton	Chloroform	Aceton- oder Estermischung[2]
1) Dauer der Vorbehandlung: 17 Stunden „ „ Auflösung: 3 1/2 Stunden					
nicht hydrolysiert	46,26	5,91	nicht	wenig	nicht
hydrolysiert	43,75	27,41	gut	gut	gut
2) Dauer der Vorbehandlung: 24 Stunden „ „ Auflösung: 1 1/2 Stunden					
nicht hydrolysiert	37,11	5,91	nur in der Wärme	unlöslich	unlöslich
hydrolysiert	64,55	20,69	gut	gut	gut

[1] Zeitschr. f. angew. Chem. *19.* 994 (1906).

[2] Die „Estermischung" besteht aus 85 Teilen Ameisensäure-Äthylester und 15 Teilen Milchsäure-Äthylester.

Azetyl-cellulose	Azetyl-Gehalt	Kupfer-Zahl	Löslichkeit		
			Aceton	Chloroform	Aceton- oder Estermischung
3) Dauer der Vorbehandlung: 48 Stunden „ „ Auflösung: 20 Minuten					
nicht hydrolysiert	29,09	10,44	unlöslich	unlöslich	—
hydrolysiert	57,02	30,53	gut	gut	—
4) Dauer der Vorbehandlung: 72 Stunden „ „ Auflösung: 10 Minuten					
nicht hydrolysiert	41,36	4,06	unlöslich	unlöslich	—
hydrolysiert	51,64	33,16	gut	gut	—

Je länger die Vorbehandlung dauerte, umso rascher vollzieht sich die Auflösung. Aber die eigentliche Veresterung ist dann nicht immer auch schon beendet; gelegentlich hat sie noch nicht einmal die Stufe des Diacetats erreicht. Die darauffolgende „Hydrolyse" ist *dann* zugleich auch noch weitere Veresterung; und gerade dann schiesst sie zugleich auch noch über das Triacetat hinaus, trotzdem das 12-stündige Erhitzen auf 50° eine milde Hydrolysierbedingung darstellt. Immer wächst der Reduktionswert gegen Fehlingsche Lösung ausserordentlich stark an. In allen Fällen stellten die Verdunstungsrückstände unbrauchbare, zum Teil schon beim Trocknen zerspringende Häute dar.

Von allen genannten Vorbehandlungsweisen hatte sich also diejenige mit Eisessig allein noch am besten bewährt. Noch günstiger und zuverlässiger wirkt es, wenn dem Eisessig gleich auch als Azetylierungskatalysator das Natriumbisulfat oder Chlorzink zugefügt wird. Man arbeitet dann in folgender Weise:

Zu 5 g Cellulose wird eine Lösung von 20 g Essigsäure (100 %), 0,5 g Wasser und 0,5 g Natriumbisulfat gesetzt. Diese Mischung wird während 17 Stunden bei 50—70° erwärmt. Danach rührt man in die gekühlte Mischung 25 g Essigsäureanhydrid ein. Die Temperatur darf dabei nicht über 60° steigen. Man erhält auf diese Weise eine viskose Lösung. Durch Erwärmung der Reaktionsmischung bei 70° während kurzer Zeit (ungefähr eine halbe Stunde) wird die Reaktion beendet. Dann wird etwas abgekühlt. Man setzt 5,5—6 ccm Wasser zu und lässt die Mischung während 65—70 Stunden bei 50° stehen. Durch Eingiessen der Lösung in überschüssiges Wasser wird ein in Chloroform unlösliches, aber in Aceton lösliches Produkt ausgefällt.

4. FILTRIERPAPIER ALS AUSGANGSMATERIAL.

Über Azetylierungen von Filtrierpapier hat Ost 1906 einige Angaben veröffentlicht. Er scheint bei seinen Versuchen keine Besonderheiten gegenüber der Watte als Ausgangsmaterial gefunden zu haben.

Wir wandten auf das Filtrierpapier (Schleicher-Schüll) dieselben Verfahren an, die wir mit dem gereinigten Sulfitzellstoff durchprobierten. Zunächst also versuchten wir die aus der salzsauren Lösung durch Wasser ausgefällte Cellulose zu verwenden. Die Kupferzahlen der Papiere schwankten in verschiedenen Proben zwischen 1 und 3. Wenn die in der zehnfachen Menge 40 %-iger Salzsäure aufgenommene Cellulose nach 10 Minuten langem Verweilen in der filtrierten Lösung mit Wasser gefällt wurde, kam sie mit einer Kupfer-Zahl von 17,7 unkorr., 13,9 korrigiert wieder heraus; bei einstündiger Einwirkungsdauer der Salzsäure stieg dieser Wert auf 28,0, bezw. 22,8, als wahre Kupferzahl. In entsprechender Höhe hielten sich die Reduktionswerte der damit erzeugten Azetylcellulosen, und wie immer in solchen Fällen ergaben sich nur spröde Films. Dabei können die Azetylgehalte bei verschiedenen Ansätzen zwischen den

Werten für Di- und für Tetraacetat schwanken. Zum Beispiel wurden 5 g der wie oben beschrieben erhaltenen Cellulose von der Kupferzahl 22,$_{8}$ nach Auswaschen mit kaltem Eisessig getrocknet und mit 20 g Eisessig, 25 g Essigsäureanhydrid und 0,$_{2}$ g conc. Schwefelsäure gemischt. Nach 6 Stunden bei Zimmertemperatur war Auflösung eingetreten. Darauf folgte die Hydrolyse mit 4 g Wasser bei 50°. Dauerte sie 48 Stunden, so zeigte die Ausfällung einen Azetylgehalt von 50,$_{2}$ % und die Kupferzahl 20,$_{2}$; nach 60 stündiger Hydrolyse einer anderen, im übrigen genau so behandelten Probe war der Azetylgehalt 37,$_{3}$ %, die Kupferzahl 19,$_{66}$.

Auch für Filtrierpapier erwies sich schliesslich diejenige Arbeitsweise als sicherste, welche wir oben für Sulfitzellstoff angegeben haben: Vorbehandlung mit Eisessig und Natriumbisulfat, bezw. Chlorzink, möglichst kurze Azetylierung bei 65°, Hydrolyse während dreier Tage bei 65—70°. Sie führt dann zu Triacetaten mit niedrigen Kupferzahlen, aus deren Lösungen in der Acetonmischung gute, elastische, dauerhafte Films gewonnen werden können.

Wissenschaftliches Laboratorium der Th. Goldschmidt A. G., Essen und Mannheim—Rheinau.

ACTA ACADEMIAE ABOENSIS
MATHEMATICA ET PHYSICA I: 7

ÜBER EINE
VERALLGEMEINERUNG DES EUKLIDISCHEN ALGORITHMUS

VON
NILS PIPPING
DR. PHIL., LEKTOR DER MATHEMATIK AN DER AKADEMIE ÅBO (FINLAND)

ÅBO AKADEMI
ÅBO 1922

ÅBO 1922
ÅBO TRYCKERI OCH TIDNINGS AKTIEBOLAG

ÜBER EINE VERALLGEMEINERUNG DES EUKLIDISCHEN ALGORITHMUS.

1. Wir betrachten ein System von drei *positiven* reellen Werten

$$t_0 \geqq t_1 \geqq t_2.$$

Falls sie alle unter einander *verschieden* sind, bilden wir aus dem gegebenen System zwei neue Systeme nach der folgenden Regel.

Das μ:te System ($\mu = 1, 2$) geht hervor, indem der grösste Wert, t_0, durch den Wert $t_0 - t_\mu$ ersetzt wird, während die Werte t_1, t_2 unverändert gelassen werden.

Die so gebildeten Systeme bestehen aus drei *positiven* Werten; falls jedes derselben nur unter einander *verschiedene* Werte enthält, wiederholen wir dasselbe Verfahren in Bezug auf alle beide. Hierbei erhalten wir 2^2 neue Systeme, u. s. w. Bei dem ν:ten Schritte gehen 2^ν neue Systeme hervor.

So lange kein einziges von den betrachteten Systemen zwei *gleiche* Werte enthält, setzen wir das genannte Rekursionsverfahren fort; die bei dem folgenden Schritte hervorgehenden Systeme bestehen dann aus lauter *positiven* Werten. Falls wir aber ein System bekommen, das zwei *gleiche* Werte enthält, brechen wir das Verfahren ab; in diesem Falle sagen wir daher, dass der Algorithmus *abbricht;* sonst lässt er sich ins *Unendliche* fortsetzen.

Es sei ω eine positive reelle Grösse, und wir wenden den obigen

Algorithmus auf die Potenzen $1, \omega, \omega^2$ an. Hierbei erhalten wir eine Kette von Systemen

$$\underbrace{\underbrace{S_1^{(2)} \quad S_2^{(2)}}_{S_1^{(1)}} \qquad \underbrace{S_3^{(2)} \quad S_4^{(2)}}_{S_2^{(1)}}}_{S_1^{(0)}}$$
$$\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots\cdots$$

welche wir *die zu ω gehörige allgemeine Kette 2:ter Ordnung* nennen.[1]

Im folgenden setzen wir diese Kette als *unendlich* voraus, und wir bezeichnen sie kurz mit K. Von der Kette K greifen wir eine Reihe von Systemen

$$S_1^{(0)},\ S_{\nu_1}^{(1)},\ S_{\nu_2}^{(2)},\ S_{\nu_3}^{(3)},\ \ldots.$$

in der Weise heraus, dass jedes System $S_{\nu_\mu}^{(\mu)}$ eines der beiden Systeme ist, welche aus dem System $S_{\nu_{\mu-1}}^{(\mu-1)}$ hergeleitet wurden.

Diese Kette nennen wir eine *Unterkette* der allgemeinen Kette K. Wir wollen darlegen, *dass die von Jacobi angegebene Verallgemeinerung des Euklidischen Algorithmus eine Reihe von Systemen gibt, die sämtlich in derselben Unterkette der Kette K vorkommen.*

Mit Hilfe der Gleichungen

$$\text{(a)}\quad u_{\nu+1} = v_\nu - l_\nu u_\nu,\ v_{\nu+1} = w_\nu - m_\nu u_\nu,\ w_{\nu+1} = u_\nu,\ (\nu = 0, 1, 2, \cdots),$$

in denen l_ν und m_ν die grössten ganzen Zahlen bedeuten, welche $\leqq v_\nu : u_\nu$, bzw. $w_\nu : u_\nu$ sind, leitet Jacobi — wie bekannt — aus den Ausgangswerten $u_0 = 1$, $v_0 = \omega$, $w_0 = \omega^2$ sukzessiv neue Wertesysteme her.

[1] Eine allgemeine Kette n:ter Ordnung ergibt sich, wenn wir von dem Wertesystem $1, \omega, \omega^2, \ldots, \omega^n$ ausgehen, aus demselben n neue Systeme bilden, aus diesen wieder n^2 neue Systeme, u. s. w. (Vgl. Nils Pipping: Ein Kriterium für die reellen algebraischen Zahlen, auf eine direkte Verallgemeinerung des Euklidischen Algorithmus gegründet; Acta Academiae Aboensis, Mathematica et Physica I, Åbo, 1921.)

Es lässt sich ohne Mühe zeigen, dass *falls das System* u_ν, v_ν, w_ν *in der Kette* K *vorkommt, so ist dasselbe mit dem System* (a) *der Fall.*

Hierbei sind drei Möglichkeiten zu unterscheiden.

1:o. *Von den Werten* u_ν, v_ν, w_ν *ist* u_ν *der grösste.* Dieser Fall kann nur für $\nu=0$ zutreffen. Wir haben dann $u_\nu > v_\nu$, $u_\nu > w_\nu$, so dass $l_\nu = m_\nu = 0$; das System (a) ist mit dem System u_ν, v_ν, w_ν identisch und kommt mithin in der Kette K vor, w. z. b. w.

2:o. *Von den Werten* u_ν, v_ν, w_ν *ist* u_ν *der mittlere.* Es ist dann $w_\nu > u_\nu > v_\nu$; denn falls wir $v_\nu > u_\nu > w_\nu$ hätten, würde aus der letzteren von diesen Ungleichungen folgen, dass $\nu = 0$ wäre, d. h. u_ν wäre entweder der grösste oder der kleinste von den Werten u_ν, v_ν, w_ν. Die Werte des Systems (a) sind daher

$$v_\nu,\ w_\nu - m_\nu u_\nu,\ u_\nu,$$

weil ja $l_\nu = 0$ aus der Ungleichung $u_\nu > v_\nu$ hervorgeht. Dieses Wertesystem kommt in der Kette K vor. Es ist nämlich w_ν der grösste von den Werten u_ν, v_ν, w_ν; das System $u_\nu, v_\nu, w_\nu - u_\nu$ kommt mithin in der Kette K vor, womit unsere Behauptung im Falle $m_\nu = 1$ bewiesen ist. Für $m_\nu > 1$ ist $w_\nu - u_\nu$ der grösste von den Werten u_ν, v_ν, $w_\nu - u_\nu$, woraus folgt, dass die Werte u_ν, v_ν, $w_\nu - 2u_\nu$ ein System der Kette K bilden. Vermittels vollständiger Induktion lässt sich auf dieselbe Weise schliessen, dass allgemein das System u_ν, v_ν, $w_\nu - m_\nu u_\nu$ in der Kette K vorkommt, w. z. b. w.

3:o. *Von den Werten* u_ν, v_ν, w_ν *ist* u_ν *der kleinste.* Wir subtrahieren von dem grössten der Werte u_ν, v_ν, w_ν den Wert u_ν, von dem grössten Wert des so erhaltenen Systems subtrahieren wir wieder den Wert u_ν, u. s. w. Dieses Verfahren gibt uns nach $(l_\nu + m_\nu - 2)$ Operationen das System

$$v_\nu - (l_\nu - 1)u_\nu,\ w_\nu - (m_\nu - 1)u_\nu,\ u_\nu,$$

in welchem die beiden erstgeschriebenen Werte noch immer $> u_\nu$ sind. Der Wert u_ν von dem grösseren der beiden Werte $v_\nu - (l_\nu - 1)u_\nu$,

$w_\nu - (m_\nu - 1)u_\nu$ subtrahiert, gibt ein System mit dem zweiten derselben als grösstem Wert. Wenn wir von diesem noch den Wert u_ν subtrahieren, erhalten wir endlich das System (a), welches also in der Kette K vorkommt, w. z. b. w.

Aus den obigen Erwägungen geht ferner folgendes hervor: das System (a) stammt sozusagen von dem System u_ν, v_ν, w_ν her, d. h. das System (a) ist eines von den Systemen, welche entweder direkt oder durch gewisse zwischenliegende Systeme aus dem System u_ν, v_ν, w_ν hergeleitet wurden. Weil $S_1^{(0)} = (1,\ \omega,\ \omega^2) = (u_0,\ v_0,\ w_0)$ ist, haben wir mithin das Ergebnis gewonnen:

Die Wertesysteme der Jacobi-Kette kommen sämtlich in derselben Unterkette der Kette K vor.

2. *Die Kette K wird periodisch genannt, falls es in derselben eine Unterkette gibt, welche zwei Systeme enthält, deren Werte proportional sind.*

Nach dem in Nr. 1 dargelegten fällt mithin die zu ω gehörige allgemeine Kette K dann immer periodisch aus, wenn die zur fraglichen Grösse ω gehörige Jacobi-Kette einen periodischen Verlauf hat. Bezüglich aller Beispiele, für welche eine periodische Jacobi-Kette hergeleitet wurde, lässt sich daher sofort schliessen, dass auch die Kette K periodisch ist.

Ferner wollen wir zeigen, dass *falls die zu ω gehörige allgemeine Kette (2:ter Ordnung) periodisch ausfällt, so ist ω eine algebraische Zahl 3:ten Grades.*

Diejenige Unterkette, welche unserer Annahme gemäss zwei Systeme enthält, deren Werte proportional sind, bezeichnen wir mit

$$S_0,\ S_1,\ S_2,\ \cdots,$$

und es seien u_ν, v_ν, w_ν die drei Werte, welche dem System S_ν gehören.

Wir dürfen hierbei

$$u_0 = 1,\ v_0 = \omega,\ w_0 = \omega^2$$

wählen, und allgemein: wenn wir aus dem System $S_{\nu-1}$ das System S_ν herleiten, ersetzen wir den grössten Wert jenes Systems durch einen neuen Wert nach der in Nr. 1 angegebenen Regel *ohne die gegenseitige Reihenfolge der fraglichen Werte zu verändern;* u_ν, v_ν, w_ν bezeichnen dann eindeutig definierte Werte.

Es lassen sich die Werte des Ausgangssystems S_0 in der Form

$$\begin{aligned} u_0 &= 1 = 1 + 0 \cdot \omega + 0 \cdot \omega^2 = p_0 + p_0' \omega + p_0'' \omega^2 \\ v_0 &= \omega = 0 + 1 \cdot \omega + 0 \cdot \omega^2 = q_0 + q_0' \omega + q_0'' \omega^2 \\ w_0 &= \omega^2 = 0 + 0 \cdot \omega + 1 \cdot \omega^2 = r_0 + r_0' \omega + r_0'' \omega^2 \end{aligned}$$

schreiben, und falls wir sukzessiv mit sämtlichen Koeffizienten p, q, r dieselben Operationen ausführen wie mit den entsprechenden Werten u, v, w, erhalten wir daher die Gleichungen

$$\begin{aligned} u_\nu &= p_\nu + p_\nu' \omega + p_\nu'' \omega^2 \\ v_\nu &= q_\nu + q_\nu' \omega + q_\nu'' \omega^2 \\ w_\nu &= r_\nu + r_\nu' \omega + r_\nu'' \omega^2 \end{aligned} \tag{1}$$

mit *ganzzahligen* Koeffizienten p, q, r.

Dem obigen gemäss ist die Determinante dieses Gleichungssystems gleich $+1$, und wir erhalten mithin

$$\begin{aligned} 1 &= P_\nu u_\nu + Q_\nu v_\nu + R_\nu w_\nu \\ \omega &= P_\nu' u_\nu + Q_\nu' v_\nu + R_\nu' w_\nu \\ \omega^2 &= P_\nu'' u_\nu + Q_\nu'' v_\nu + R_\nu'' w_\nu, \end{aligned} \tag{2}$$

wenn wir wie gewöhnlich die Unterdeterminanten mit P_ν, Q_ν, R_ν, P_ν', Q_ν', R_ν', P_ν'', Q_ν'', R_ν'' bezeichnen.

Es seien die Werte u_ν, v_ν, w_ν der Grösse nach geordnet $\alpha_\nu > \beta_\nu > \gamma_\nu$, wobei

$$\begin{aligned} \alpha_\nu &= a_\nu + a_\nu' \omega + a_\nu'' \omega^2 \\ \beta_\nu &= b_\nu + b_\nu' \omega + b_\nu'' \omega^2 \\ \gamma_\nu &= c_\nu + c_\nu' \omega + c_\nu'' \omega^2. \end{aligned} \tag{1$'$}$$

Wenn wir dieses Gleichungssystem auflösen und die Unterdeterminanten mit A_ν, B_ν, C_ν, A_ν', B_ν', C_ν', A_ν'', B_ν'', C_ν'' bezeichnen, erhalten wir [vgl. (2)]

$$(2)' \qquad \begin{aligned} \pm 1 &= A_\nu \alpha_\nu + B_\nu \beta_\nu + C_\nu \gamma_\nu \\ \pm \omega &= A_\nu' \alpha_\nu + B_\nu' \beta_\nu + C_\nu' \gamma_\nu \\ \pm \omega^2 &= A_\nu'' \alpha_\nu + B_\nu'' \beta_\nu + C_\nu'' \gamma_\nu, \end{aligned}$$

in welchen Gleichungen die linken Glieder entweder alle drei positiv oder alle drei negativ sind.

Nehmen wir jetzt an, es sei $\alpha_k : \beta_k : \gamma_k = \alpha_l : \beta_l : \gamma_l$; $(l > k)$, so dass

$$(3) \qquad \frac{\alpha_l}{\alpha_k} = \frac{\beta_l}{\beta_k} = \frac{\gamma_l}{\gamma_k} = \Theta; \ (0 < \Theta < 1).$$

Nach (2)′ und (3) erhalten wir dann

$$\begin{aligned} \pm \Theta &= A_k \alpha_l + B_k \beta_l + C_k \gamma_l = a + b\omega + c\omega^2 \\ \pm \Theta\omega &= A_k' \alpha_l + B_k' \beta_l + C_k' \gamma_l = d + e\omega + f\omega^2 \\ \pm \Theta\omega^2 &= A_k'' \alpha_l + B_k'' \beta_l + C_k'' \gamma_l = g + h\omega + i\omega^2, \end{aligned}$$

wo $a, b, c, d, e, f, g, h, i$ ganze Zahlen bedeuten, und nach Elimination von Θ gehen daher zwei kubische Gleichungen mit ganzzahligen Koeffizienten hervor:

$$\begin{aligned} c\omega^3 + (b - f)\omega^2 + (a - e)\omega - d &= 0 \\ f\omega^3 + (e - i)\omega^2 + (d - h)\omega - g &= 0. \end{aligned}$$

Beide können nicht Identitäten sein. Denn in diesem Falle wäre $c = d = f = g = b = h = 0$; $a = e = i = \pm \Theta$, d. h. Θ wäre eine *ganze* Zahl, was mit (3) in Widerspruch steht.

Wir haben mithin bewiesen, dass ω eine algebraische Zahl, *höchstens* vom 3:ten Grade ist. Weil aber die betrachtete Kette — unserer Annahme gemäss — nicht abbricht, kann ω keine algebraische Zahl 1:sten oder 2:ten Grades sein (vgl. die auf Seite 4 zitierte Abhandlung), woraus folgt, dass ω tatsächlich eine kubische Irrationalzahl ist.

3. *O. Perron* [1] hat wie bekannt gezeigt, dass die Jacobi-Kette konvergiert. Wir fragen jetzt, ob dasselbe mit einer beliebigen Unterkette der Kette K der Fall ist. Wir fragen m. a. W., ob allgemein die Beziehungen

$$
\begin{aligned}
&\lim_{\nu=\infty} \frac{P_\nu'}{P_\nu} = \lim_{\nu=\infty} \frac{Q_\nu'}{Q_\nu} = \lim_{\nu=\infty} \frac{R_\nu'}{R_\nu} = \omega \\
&\lim_{\nu=\infty} \frac{P_\nu''}{P_\nu} = \lim_{\nu=\infty} \frac{Q_\nu''}{Q_\nu} = \lim_{\nu=\infty} \frac{R_\nu''}{R_\nu} = \omega^2
\end{aligned} \tag{4}
$$

gültig sind.

Es ist leicht darzutun, dass dem so *nicht* ist. Zu dem Ende brauchen wir nur den Zusammenhang zwischen den Zahlen $P_\nu, \cdots, R_\nu''$ und den Zahlen $P_{\nu+1}, \ldots, R''_{\nu+1}$ zu untersuchen.

Nehmen wir einen Augenblick an, dass die Werte u_ν, v_ν, w_ν der Grösse nach geordnet $w_\nu > v_\nu > u_\nu$ sind, und dass wir als Subtrahenden den Wert v_ν wählen, um aus dem System S_ν das System $S_{\nu+1}$ herzuleiten. Wir haben dann

$$
\begin{array}{llll}
u_{\nu+1} = u_\nu & p_{\nu+1} = p_\nu & p'_{\nu+1} = p'_\nu & p''_{\nu+1} = p''_\nu \\
v_{\nu+1} = v_\nu & q_{\nu+1} = q_\nu & q'_{\nu+1} = q'_\nu & q''_{\nu+1} = q''_\nu \\
w_{\nu+1} = w_\nu - v_\nu, & r_{\nu+1} = r_\nu - q_\nu, & r'_{\nu+1} = r'_\nu - q'_\nu, & r''_{\nu+1} = r''_\nu - q''_\nu,
\end{array}
$$

und daher

$$
\begin{array}{lll}
P_{\nu+1} = P_\nu & P'_{\nu+1} = P'_\nu & P''_{\nu+1} = P''_\nu \\
Q_{\nu+1} = Q_\nu + R_\nu & Q'_{\nu+1} = Q'_\nu + R'_\nu & Q''_{\nu+1} = Q''_\nu + R''_\nu \\
R_{\nu+1} = R_\nu, & R'_{\nu+1} = R'_\nu, & R''_{\nu+1} = R''_\nu .
\end{array}
$$

Ähnliche Beziehungen erhält man, falls die Werte u_ν, v_ν, w_ν der Grösse nach geordnet in einer anderen Reihe aufeinanderfolgen, oder falls wir als Subtrahenden nicht den mittleren sondern den kleinsten von den Werten u_ν, v_ν, w_ν wählen. Wir sehen allgemein, dass

[1] Siehe Mathematische Annalen, Bd. 64, 1907.

von den Zahlen $P_\nu, \cdots, R_\nu''$ nur diejenige, welche in den Gleichungen (2) Koeffizienten des Subtrahenden u_ν, v_ν oder w_ν sind, verändert werden.

Bei der Wahl des Subtrahenden sind stets zwei Möglichkeiten offen. Wir können folglich für jeden Index ν z. B. den Wert u_ν als Subtrahenden vermeiden. Es ist dann

$$P_\nu = P_0 = 1,\ P_\nu' = P_0' = 0,\ P_\nu'' = P_0'' = 0;\ (\nu = 0, 1, 2, \cdots),$$

und wir haben folglich *nicht*

$$\lim_{\nu=\infty} \frac{P_\nu'}{P_\nu} = \omega,\ \lim_{\nu=\infty} \frac{P_\nu''}{P_\nu} = \omega^2.$$

4. Betrachten wir aber speziell diejenige Unterkette

$$S_0,\ S_1,\ S_2,\ \cdots,$$

welche sich ergibt, wenn wir bei jedem Schritt den mittleren der Werte u_ν, v_ν, w_ν von dem grössten derselben subtrahieren; für die so gebildete Kette sind die Beziehungen (4) tatsächlich gültig, was wir nunmehr beweisen werden.

Zu dem Ende schreiben wir die Werte u_ν, v_ν, w_ν in die untenstehende Tabelle I auf, und daneben schreiben wir eine andere Tabelle II auf, worin $\alpha_\nu^{(1)}$, $\alpha_\nu^{(2)}$, $\alpha_\nu^{(3)}$ $(\nu = 0, 1, 2, \cdots)$ eine gewisse Permutation der Ziffern 1, 2, 3 angibt; dem grössten (bzw. dem mittleren und dem kleinsten) von den Werten u_ν, v_ν, w_ν der Tabelle I entspricht auf demselben Platz in der Tabelle II die Ziffer 1 (bzw. 2 und 3).

Tabelle I.

u_0	v_0	w_0
u_1	v_1	w_1
u_2	v_2	w_2
.	.	.
.	.	.
.	.	.

Tabelle II.

$\alpha_0^{(1)}$	$\alpha_0^{(2)}$	$\alpha_0^{(3)}$
$\alpha_1^{(1)}$	$\alpha_1^{(2)}$	$\alpha_1^{(3)}$
$\alpha_2^{(1)}$	$\alpha_2^{(2)}$	$\alpha_2^{(3)}$
.	.	.
.	.	.
.	.	.

Nach dem Bildungsgesetz der betrachteten Kette bleibt — mit Rücksicht auf das Axiom von Archimedes — kein Wert u, v oder w fortwährend der kleinste, sondern es gibt sicher einen Index ν_1 derart, dass wenigstens einer von den Werten u_{ν_1}, v_{ν_1}, w_{ν_1} kleiner als der kleinste von den Werten u_{ν_1-1}, v_{ν_1-1}, w_{ν_1-1} ist. Und weil bei der Herleitung jedes neuen Systems *nur einer* von den Werten u_ν, v_ν, w_ν verändert wird, hat nur einer von den Werten u_{ν_1}, v_{ν_1}, w_{ν_1} die genannte Eigenschaft. *Auf eine gewisse endliche Anzahl aufeinanderfolgender Ziffern* 3 *folgt also in jeder Kolonne die Ziffer* 2.

In ganz derselben Weise geht hervor, *dass auf eine gewisse endliche Anzahl aufeinanderfolgender Ziffern* 2 *in jeder Kolonne die Ziffer* 1 *folgt.*

Nach dem Bildungsgesetz der betrachteten Kette bleibt ferner — mit Rücksicht auf das Axiom von Archimedes — kein Wert u, v oder w fortwährend der grösste. *Auf eine gewisse endliche Anzahl aufeinanderfolgender Ziffern* 1 *folgt also in jeder Kolonne die Ziffer* 2 *oder die Ziffer* 3.

Aus obigen Erwägungen stellt sich heraus, dass *falls wir eine genügend grosse, jedoch endliche Anzahl von aufeinanderfolgenden Zeilen der Tabelle II betrachten, so kommt sowohl die Ziffer* 1 *als auch die Ziffer* 2 *in allen drei Kolonnen vor.*

Aus diesem Ergebnis lässt sich ferner schliessen, dass die Beziehungen

$$\lim_{\nu=\infty} P_\nu = \lim_{\nu=\infty} Q_\nu = \lim_{\nu=\infty} R_\nu = \infty \tag{5}$$

gelten.

Um die Zahlen P_ν, Q_ν, R_ν sukzessiv aus den Ausgangswerten

$$P_0 = 1,\ Q_0 = 0,\ R_0 = 0$$

herzuleiten, haben wir nach den Untersuchungen in Nr. 3 auf folgende Weise zu verfahren:

Der Koeffizient des mittleren von den Werten u_ν, v_ν, w_ν *in der*

Gleichung $1 = P_\nu u_\nu + Q_\nu v_\nu + R_\nu w_\nu$ *wird durch die Summe von jener selben Zahl und dem Koeffizienten des grössten Wertes* u_ν, v_ν, w_ν *ersetzt, während die beiden übrigen von den Zahlen* P_ν, Q_ν, R_ν *unverändert gelassen werden; hierbei gehen die Zahlen* $P_{\nu+1}$, $Q_{\nu+1}$, $R_{\nu+1}$ *hervor.*

Es sind mithin P_ν, Q_ν, R_ν ganze Zahlen $\geqq 0$; und von einem gewissen Index ν an sind sie tatsächlich *positiv.*

Anfangs, die Zahlen P_ν sind sämtlich positiv, weil $P_0 > 0$ ist.

Es bezeichne ferner ν_1 die erste Zeile der Tabelle II, welche die Ziffer 1 in der ersten Kolonne aufweist. Dann sind

a) die Zahlen Q_{ν_1+1}, Q_{ν_1+2}, $\cdots$ sämtlich positiv, falls die Ziffern der Zeile ν_1 in der Reihe 1, 2, 3 aufeinanderfolgen;

b) die Zahlen R_{ν_1+1}, R_{ν_1+2}, $\cdots$ sämtlich positiv, falls die Ziffern der Zeile ν_1 in der Reihe 1, 3, 2 aufeinanderfolgen.

Und endlich: im Falle a) sind die Zahlen Q_{ν_2+1}, Q_{ν_2+2}, $\cdots$ sämtlich positiv, wenn ν_2 $(\nu_2 > \nu_1)$ die erste Zeile angibt, welche die Ziffer 2 in der 3:ten Kolonne aufweist; im Falle b) sind die Zahlen R_{ν_2+1}, R_{ν_2+2}, $\cdots$ sämtlich positiv, wenn $\nu_2 (\nu_2 > \nu_1)$ die erste Zeile angibt, welche die Ziffer 2 in der 2:ten Kolonne aufweist.

Wir haben mithin

$$P_\nu, \ Q_\nu, \ R_\nu \geqq 1 \text{ für } \nu > \nu_2.$$

Ferner bestimmen wir eine Zahl ν_3 derart, dass die Zeilen der Tabelle II vom (ν_2+1):sten bis zum ν_3:ten die Ziffer 2 in allen drei Kolonnen aufweisen; dann ist

$$P_\nu, \ Q_\nu, \ R_\nu \geqq 2 \text{ für } \nu > \nu_3.$$

Auf dieselbe Weise erhalten wir allgemein

$$P_\nu, \ Q_\nu, \ R_\nu \geqq N \text{ für } \nu > \nu_{N+1},$$

womit die Beziehungen (5) als richtig erwiesen sind.

Wir setzen nunmehr

$$
(6)\qquad
\begin{aligned}
d_\nu &= P_\nu' - \omega P_\nu & \qquad \bar{d}_\nu &= P_\nu'' - \omega^2 P_\nu \\
\delta_\nu &= Q_\nu' - \omega Q_\nu & \qquad \bar{\delta}_\nu &= Q_\nu'' - \omega^2 Q_\nu \\
\Delta_\nu &= R_\nu' - \omega R_\nu, & \qquad \bar{\Delta}_\nu &= R_\nu'' - \omega^2 R_\nu.
\end{aligned}
$$

Den grössten von den Werten $|d_\nu|$, $|\delta_\nu|$, $|\Delta_\nu|$ bezeichnen wir mit M_ν, den grössten von den Werten $|\bar{d}_\nu|$, $|\bar{\delta}_\nu|$, $|\bar{\Delta}_\nu|$ mit $\bar{M}_\nu$, und wir behaupten, dass

$$
(7)\qquad M_{\nu+1} \leqq M_\nu, \quad \bar{M}_{\nu+1} \leqq \bar{M}_\nu.
$$

Nehmen wir wieder einen Augenblick an, dass die Werte u_ν, v_ν, w_ν der Grösse nach geordnet $w_\nu > v_\nu > u_\nu$ sind, und dass wir als Subtrahenden den Wert v_ν wählen, um aus dem System S_ν das System $S_{\nu+1}$ herzuleiten. Mit Rücksicht auf die Untersuchungen in Nr. 3 haben wir dann nach (6)

$$
\begin{aligned}
d_{\nu+1} &= d_\nu & \qquad \bar{d}_{\nu+1} &= \bar{d}_\nu \\
\delta_{\nu+1} &= \delta_\nu + \Delta_\nu & \qquad \bar{\delta}_{\nu+1} &= \bar{\delta}_\nu + \bar{\Delta}_\nu \\
\Delta_{\nu+1} &= \Delta_\nu, & \qquad \bar{\Delta}_{\nu+1} &= \bar{\Delta}_\nu.
\end{aligned}
$$

Die Richtigkeit unserer Behauptung geht folglich hervor, falls wir beweisen können, dass

$$
|\delta_\nu + \Delta_\nu| < M_\nu, \qquad |\bar{\delta}_\nu + \bar{\Delta}_\nu| < \bar{M}_\nu.
$$

Es ist nach (2) und (6)

$$
u_\nu d_\nu + v_\nu \delta_\nu + w_\nu \Delta_\nu = 0,
$$

und weil $u_\nu \neq 0$, erhalten wir daher

$$
(8)\qquad d_\nu = -\left(\frac{v_\nu}{u_\nu}\delta_\nu + \frac{w_\nu}{u_\nu}\Delta_\nu\right).
$$

Nunmehr sind zwei Fälle zu unterscheiden:[1]

$$1{:}o\ \delta_\nu \Delta_\nu < 0 \text{ und } 2{:}o\ \delta_\nu \Delta_\nu > 0.$$

Falls $\delta_\nu \Delta_\nu < 0$ ist, haben wir $|\delta_\nu + \Delta_\nu| < \max.(|\delta_\nu|, |\Delta_\nu|) \leqq M_\nu$, w. z. b. w.

Falls aber $\delta_\nu \Delta_\nu > 0$ ist, ergibt sich nach (8)

$$|d_\nu| = \frac{v_\nu}{u_\nu}|\delta_\nu| + \frac{w_\nu}{u_\nu}|\Delta_\nu| > |\delta_\nu| + |\Delta_\nu| = |\delta_\nu + \Delta_\nu|,$$

und wir haben mithin auch in diesem Falle $|\delta_\nu + \Delta_\nu| < M_\nu$, w. z. b. w.

Auf ganz dieselbe Weise leiten wir die Ungleichung $|\bar{\delta}_\nu + \bar{\Delta}_\nu| < \bar{M}_\nu$ her, und es gelten mithin die Beziehungen (7) unter den oben (vgl. S. 13) gemachten Voraussetzungen betreffend die Werte u_ν, v_ν, w_ν. Falls diese Werte der Grösse nach geordnet in einer anderen Reihe aufeinanderfolgen, oder falls wir als Subtrahenden nicht den mittleren sondern den kleinsten von denselben wählen, ergibt sich die Richtigkeit jener Beziehungen in analoger Weise.

Nach (7) haben wir für jeden Index ν

$$\begin{aligned} d_\nu, \ \delta_\nu, \ \Delta_\nu &\leqq M_0 = \max.(1, \omega) \\ \bar{d}_\nu, \ \bar{\delta}_\nu, \ \bar{\Delta}_\nu &\leqq \bar{M}_0 = \max.(1, \omega^2). \end{aligned} \tag{9}$$

Die Beziehungen (9), (6) und (5) zusammengestellt geben den verlangten Konvergenzsatz (4). —

Die in dieser Nummer betrachtete spezielle Kette wurde von Viggo Brun (En generalisation av kjedebrøken I, II; Videnskapsselskapets Skrifter, Kristiania, 1919, 1920) angegeben. Auf geometrischem Wege zeigt Brun u. A., dass *wenigstens eine* von den Quoten $P_\nu' : P_\nu$, $Q_\nu' : Q_\nu$, $R_\nu' : R_\nu$ mit wachsendem Index ν gegen ω konvergiert, und dass ebenso *wenigstens eine* von den Quoten $P_\nu'' : P_\nu$, $Q_\nu'' : Q_\nu$, $R_\nu'' : R_\nu$ mit wachsendem Index ν gegen ω^2 konvergiert.

Åbo, den 28. Januar 1922.

[1] Es ist $\delta_\nu \Delta_\nu \neq 0$, weil die betrachtete Kette unserer Annahme gemäss nicht abbricht, und ω mithin keine rationale Zahl ist. (Vgl. S. 8.)

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